# Edexcel BTEC Levels 4 and 5 Higher Nationals specification in Applied Chemistry

## Contents

# Unit 1: Inorganic Chemistry

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|---|---|
| Unit code: | R/601/0349 |
| Level: | 4 |
| Credit value: | 15 |

## Aim

This unit covers the foundations of inorganic chemistry relating to structure and bonding, together with the chemistry of important elements and compounds and a review of some major industrial applications.

## Unit abstract

The unit provides a comprehensive coverage of basic inorganic chemistry and lays a firm foundation for studying chemistry at higher levels. The unit applies the principles of inorganic chemistry to aspects of structure and bonding and the chemistry of selected elements and compounds. These, together with a survey of important industrial applications, form a firm foundation for employees working in the chemistry field or for learners hoping to gain such employment or progress to higher levels of study.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the structure of atoms

2 Understand the structure of matter

3 Understand the chemistry of elements and compounds

4 Be able to review the industrial applications of elements and compounds.

# Unit content

1 **Understand the structure of atoms**

*Historical development*: Dalton's work; JJ Thompson and electrons; Robert Millikan and electron charge; Rutherford and Geiger-Marsden's work (α particle deflections)

*The spectrum of atomic hydrogen*: characteristics of electromagnetic radiation; wavelength; amplitude; frequency; simple calculations using $c = f\lambda$ and Planck's equation; Bohr model; spectral series (Lyman, Balmer); the Rydberg equation (including associated calculations)

*The quantum mechanical model*: wave particle duality (de Broglie's relation); Heisenberg uncertainty principle; solutions to the Schrödinger equation (qualitative only)

*The electronic structure of atoms*: electronic configurations (spdf) of elements 1 to 36 (Aufbau); shapes and orientation of s, p and d orbitals; atomic orbitals in terms of principal quantum number, orbital angular momentum quantum number and magnetic quantum number; Pauli exclusion principle in terms of electron quantum numbers; Hund's rule

*The Periodic Table and electronic structure*: structure of Periodic Table in terms of s block, p block, d block and f block; ionisation energies and trends across periods 2 and 3; ionisation energies and trends down groups; electron affinity (definition and examples)

*Atomic radii*: covalent, metallic, ionic and Van der Waals radii; trends in radii across periods and down groups

2 **Understand the structure of matter**

*Ionic bonding*: formation of ionic compounds eg Born Haber cycles; properties of ionic compounds; polarisation and covalency; Fajan rules; role of electronegativity difference in determining ionic/covalent bonding

*Metallic bonding*: metallic bonding using the electron sea model; electrical conductivity; thermal conductivity

*Covalent bonding*: bond length; bond order; bond enthalpy; bond polarity; polar molecules; dative covalent (coordinate) bonding

*Intermolecular forces of attraction*: causes, occurrence and relative strengths; dispersion forces; dipole-dipole; hydrogen bonding

*Localised bond models of covalent bonding*: Lewis concepts (shared electron pairs); valence bond (resonance); hybridisation; valence shell electron pair repulsion (VSEPR) theory; VSEPR and shapes of molecules

*Delocalised bond models*: molecular orbitals; molecular orbital energy level diagrams; linear combination of atomic orbitals (LCAO) for homonuclear and simple heteronuclear diatomic molecules; bond order and bond strength

*Types of structure*: formation, structure and typical properties of ionic and metal crystal structures; simple molecular and giant covalent (macromolecular); explanation of properties in terms of bonding and intermolecular forces

3 **Understand the chemistry of elements and compounds**

*The third period of the Periodic Table*: physical and chemical properties of the elements, oxides, hydrides and chlorides; interpretation of trends in terms of electronic structure and bonding

*s block, groups 1 and 2*: physical and chemical properties of the elements, oxides, chlorides, carbonates, sulfates and nitrates; anomalous behaviour of lithium and beryllium

*p block chemistry*: groups 13-16 to cover first two elements only in terms of physical and chemical properties of elements and their compounds with hydrogen, oxygen and chlorine (where appropriate); group 17 (halogens, fluorine to iodine) to include group trends (melting/boiling points, bond energy, oxidation states); anomalous nature of fluorine; formation of halides; reactions with sulfur and phosphorous; oxides; reactions with water; hydrogen halides

*The chemistry of hydrogen*: the hydrogen ($H^+$) and hydroxonium ions ($H_3O^+$); the hydride ion ($H^-$); reactions of metal hydrides; physical properties and reactions of covalent hydrides

*The chemistry of the inert gases (group 18)*: trends within the group; inability of helium and neon to form compounds; synthesis and properties of xenon fluorides, xenon oxides; dangers of radon gas

*d block, transition metals (Sc-Zn)*: trends in the physical properties of 3d metals; typical properties of transition metal compound to include formation of coloured ions; variable oxidation state; complex formation; anomalous behaviour of scandium and zinc

*Experimental work*: experimental work involving elements and compounds from the s, p or d block to support earlier content; interpret results in terms of electronic structure and bonding

4 **Be able to review the industrial applications of elements and compounds**

*Hydrogen applications*: production and applications of hydrogen and its compounds; potential use as fuel; uses of hydrogen isotopes; Haber process; conversion to methanol; industrial acids; s and p block hydrides; hydrogen peroxide

*s block applications*: industrial use of lithium (lithium greases); production and uses of sodium metal; production and uses of magnesium eg alloys; uses of calcium eg building materials

*p block*: production and applications of p block elements and their compounds including aluminium, silicon, nitrogen, sulfur, chlorine and argon

*d block*: production and applications of transition metals and their alloys including titanium, iron, nickel and copper

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the structure of atoms | 1.1 discuss the historical development of different models of the atom<br><br>1.2 explain the hydrogen spectrum using associated equations<br><br>1.3 discuss the quantum mechanical model of electron behaviour<br><br>1.4 explain the electronic configuration of elements hydrogen through to krypton<br><br>1.5 review electron structure in relation to position in Periodic Table<br><br>1.6 explain trends in atomic radii |
| LO2 Understand the structure of matter | 2.1 discuss the factors that have led to the current model of ionic bonding<br><br>2.2 explain the valence electron model of metallic bonding<br><br>2.3 explain the characteristics of covalent bonds and assess the factors that contribute to the magnitude of intermolecular forces of attraction<br><br>2.4 explain localised and delocalised models of covalent bonding<br><br>2.5 categorise substances according to structure |
| LO3 Understand the chemistry of elements and compounds | 3.1 outline the chemistry associated with period 3<br><br>3.2 explain the chemistry of selected elements and compounds of the s, p and d blocks<br><br>3.3 review the chemistry of hydrogen<br><br>3.4 explain the limited reactivity of selected group 18 elements<br><br>3.5 investigate experimentally selected elements and compounds of the s, p and d blocks to confirm their properties, using safe practices |
| LO4 Be able to review the industrial applications of elements and compounds | 4.1 review the industrial applications of hydrogen<br><br>4.2 review the industrial applications of selected s, p and d block elements |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 3: Physical Chemistry*
- *Unit 9: Inorganic Chemistry of Crystal Structures and Transition Metal Complexes*
- *Unit 14: Industrial Chemistry*
- *Unit 15: Biochemistry of Macromolecules and Metabolic Pathways*.

## Essential requirements

### Delivery

The unit should be delivered using a variety of approaches, for example lectures, demonstrations, and practical work. Delivery must integrate theoretical considerations with practical outcomes, emphasising the industrial importance of reactions and processes.

### Assessment

Assessment must confirm learners’ ability to categorise and systemise information relating to the chemistry of the elements and their compounds in terms of structural types and according to their position in the periodic table. An understanding of trends, patterns and differences within and across the s, p and d blocks of the periodic table must be demonstrated.

Where appropriate, underlying principles should be supported by practical investigation. There must be evidence of learner ability to access and research information and data and evaluate these in terms of structures, properties and trends.

### Resources

Learners will need access to advanced laboratory facilities with appropriate technical support.

### Employer engagement and vocational contexts

Where possible, site visits or invited speakers may enhance the content. It is important to integrate as many vocational examples as possible particularly in relation to learning outcomes 2 to 4.

# Unit 2: Organic Chemistry

Unit code: R/601/0352

Level: 4

Credit value: 15

## Aim

This unit develops the principles and practical techniques of organic chemistry. Rationalisation of structure and bonding is used to aid understanding of reaction mechanisms and functional group conversions.

## Unit abstract

This unit provides a comprehensive coverage of the principles of organic chemistry. These principles are used to develop aspects of structure, bonding and isomerism together with organic reaction mechanisms and functional group chemistry. Experimental methods fundamental to organic chemistry are also covered. The unit content is appropriate for employees working in chemical industry, for learners hoping to gain such employment or for learners progressing to higher levels of study.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the structure and bonding of organic compounds

2 Understand organic reaction mechanisms

3 Understand the reactions of hydrocarbons

4 Understand the reactions of mono-functional group compounds.

# Unit content

1 **Understand the structure and bonding of organic compounds**

*The structures of organic molecules*: alkanes; alkenes; alkynes; methods of representation; display/structural formula; condensed formula; skeletal/line formula; stereochemical ‘flying wedge’ formula; bond angles; bond lengths; shapes

*Bonding in organic molecules*: $sp^3$, $sp^2$, sp hybridisation; $\sigma$ and $\pi$ bonds

*Classification of organic molecules*: alkanes; alkenes; alkynes; alcohols; ethers, aldehydes; ketones; carboxylic acids; esters; acid anhydrides; acid halides; amines; amides, cyanides (nitriles); haloalkanes; cyclic alkanes/alkenes and difference to arenas; substituted arenes limited to haloarenes and phenol

*Isomerism in organic molecules*: structural isomerism; chain, positional, function group; stereoisomerism; geometric including cis/trans notation; optical isomerism including effect on plane polarised light

*Physical properties of organic molecules:* boiling/melting points in relation to intermolecular forces of dispersion, dipole-dipole, hydrogen bonding; effect of branching on boiling/melting points; solubility and insolubility in water

*Experimental methods*: distillation; fractional distillation; recrystallisation; column chromatography; use of melting points and thin layer chromatography (TLC); structure identification to include infrared spectroscopy eg identification of alcohols, carboxylic acids, carbonyl compounds; mass spectroscopy; high resolution nuclear magnetic resonance

2 **Understand organic reaction mechanisms**

*Categorise*: recognise and categorise reagents with justification (electrophiles, nucleophiles, radicals, acids, bases)

*Types of reactions*: recognise and categorise reactions with justification (addition, substitution, elimination, rearrangement, condensation)

*Reaction profile diagrams*: energy profiles; reaction coordinate; transition state; reaction intermediate; activation energy; catalysis

*Mechanisms*: use of curly arrows, one and two-electron movements; homolysis; heterolysis; free radical chlorination of methane; nucleophilic substitution ($SN_1$ and $SN_2$) reactions of haloalkanes; elimination reactions ($E_1$ and $E_2$) of haloalkanes; nucleophilic addition reactions of aldehydes and ketones; electrophilic addition reactions of alkenes including application of Markovnikov’s rule

3 **Understand the reactions of hydrocarbons**

*Alkanes*: sources; halogenation; combustion; free radical substitution reactions; uses as fuels and sources of industrial materials

*Alkenes*: electrophilic addition of hydrogen halides; Markovnikov addition; explanation of Markovnikov in terms of carbocation stability; rearrangements of carbocations; addition of halogens including in the presence of water; addition of water in the presence of acids; reaction with peroxycarboxylic acids; reaction with potassium manganate (VII); reaction with ozone; reduction with hydrogen; polymerisation

*Alkynes*: hydration; hydrogenation, Lindlar catalyst and use of sodium in liquid ammonia

4 **Understand the reactions of mono-functional group compounds**

*Haloalkanes*: nucleophilic substitution reactions with $H_2O$, $OH^-$, $CN^-$, $NH_3$, $RO^-$, $SN_1$ and $SN_2$; stereochemical consequences; elimination reactions; $E_1$ and $E_2$ reactions; elimination vs substitution; Grignard reagent formation; Grignard reactions with aldehydes, ketones; use of haloalkanes to synthesise other functional group compounds

*Alcohols and phenols*: acidity; reaction with sodium; reaction with hydrogen halides and phosphorus halides; oxidation; dehydration; halogenation of phenols; use of alcohols to synthesise other functional group compounds

*Carbonyl compounds*: aldehydes and ketones; oxidation and reduction; nucleophilic addition reactions, water, ammonia, hydrogen cyanide; haloform reaction; condensation with ammonia derivatives including the importance of 2,4 dinitrophenylhydrazine; reaction with Grignard reagents; use of aldehydes and ketones to synthesise other functional group compounds; carboxylic acids; acid/base reactions; esterification; acid halides; acid anhydrides; use of carboxylic acids to synthesise other functional group compounds

*Amines and amides*: acid/base reactions; amide formation; diazotisation; coupling of diazonium compounds; use of amines and amides to synthesise other functional group compounds

*Experimental work*: preparation of pure samples of selected functional group compounds and polymers

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the structure and bonding of organic compounds | 1.1 illustrate the structures of organic molecules<br>1.2 explain bonding in organic molecules<br>1.3 categorise organic molecules by functional group<br>1.4 discuss isomerism in organic structures<br>1.5 explain physical properties of organic molecules<br>1.6 safely use experimental methods to purify and identify organic compounds |
| LO2 Understand organic reaction mechanisms | 2.1 justify molecules or ions as nucleophiles, electrophiles, radicals, acids, bases<br>2.2 justify reactions as addition, substitution, elimination, rearrangement or condensation<br>2.3 explain terms associated with reaction profile diagrams<br>2.4 justify specified organic reactions using mechanisms to show electron movements |
| LO3 Understand the reactions of hydrocarbons | 3.1 explain the reactions of alkanes, alkenes and alkynes in terms of reaction mechanisms |
| LO4 Understand the reactions of mono-functional group compounds | 4.1 explain the reactions of haloalkanes, alcohols, carbonyl compounds and amines/amides in a functional group conversion context<br>4.2 justify substitution and elimination reactions as either unimolecular or bimolecular<br>4.3 undertake safely experimental organic reactions to produce selected compounds |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds*
- *Unit 15: Biochemistry of Macromolecules and Metabolic Pathways*.

## Essential requirements

## Delivery

Delivery must integrate theoretical considerations with practical outcomes. The industrial importance of reactions and processes must be emphasised. Some of the concepts learnt in *Unit 1: Inorganic Chemistry* should be applied in this unit to the structure and shapes of organic molecules. This can be achieved by use of molecular modelling software packages and physical models of organic molecules, particularly for showing differences in structural and stereoisomerism.

## Assessment

Assessment of learning outcome 1 must clearly demonstrate the relationship between structure and bonding and the physical properties of organic molecules and their potential to exist in isomeric forms. The types of compounds used to illustrate these aspects should be representative of those used to develop learning outcomes 3 and 4.

For learning outcome 2, assessment must confirm learners' understanding of reagent types and reaction types and the susceptibility of specific functional groups to attack by specific classes of reagents. Learners must show confidence in the use of curly arrows to represent both one and two electron movements to demonstrate reaction mechanisms across a range of organic reaction types.

In learning outcome 4, assessment emphasis should be on synthesis and interconversion of functional groups, integrated and reinforced by reaction mechanisms showing electron movements. Throughout the unit, where appropriate, practical work should be integrated with understanding theoretical principles.

## Resources

Learners will need access to advanced laboratory facilities with appropriate technical support.

The Royal Society of Chemistry website has a large range of resources from *The Molecular World* series of CD ROMs including: Molecular Modelling and Bonding; Alkenes and Aromatics; Separation, Purification and Identification; Chemical Kinetics and Mechanism; Mechanism and Synthesis.

## Employer engagement and vocational contexts

Many aspects of the content for learning outcomes 3 and 4 can be delivered in an industrial context. Universities often allow visits to their departments and such visits may be useful for exploring experimental methods, especially spectroscopic equipment.

# Unit 3: Physical Chemistry

Unit code: Y/601/0353

Level: 4

Credit value: 15

## Aim

This unit gives learners an understanding of concepts and practical techniques in physical chemistry. These include thermodynamics, reaction kinetics, conductivity, electrochemical cells and electrolysis.

## Unit abstract

There are certain key concepts in physical chemistry that underpin other strands of chemistry, such as inorganic chemistry, analytical chemistry, organic chemistry and biological processes. Learners will undertake a programme of assignment and related practical work, covering thermodynamics, reaction rate, ionic conductance, electrochemical cells and electrolysis. The emphasis is on being able to use theoretical concepts, interpretation of data and performing calculations. There is the opportunity to research commercial uses of electrolysis.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the application of the first, second and third laws of thermodynamics to predict the feasibility of reactions

2 Understand the use of rate equations to determine the order of a reaction

3 Understand ionic conductance

4 Understand the application of principles of oxidation and reduction to electrochemical systems.

# Unit content

1 **Understand the application of the first, second and third laws of thermodynamics to predict the feasibility of reactions**

*Laws of thermodynamics*: first, second and third laws

*Definition of standard enthalpy changes*: enthalpy of combustion; enthalpy of formation; enthalpy of dissociation; mean bond enthalpy; ionisation enthalpy; electron affinity; enthalpy of fusion; enthalpy of vaporisation; enthalpy of sublimation

*Calculation of entropy changes*: changes of state and heating and cooling of a single substance (including use of molar heat capacity at constant pressure and enthalpies of vaporisation and fusion)

*Calculation of $\Delta H^{\theta}$, $\Delta S^{\theta}$*: from tables of standard enthalpy changes of formation, $\Delta H_f^{\theta}$ of reactants and products and entropies of reactants and products; calculation of $\Delta H_f^{\theta}$ from mean bond enthalpies; calculation of enthalpy changes involving standard enthalpy of combustion

Enthalpy changes at different temperatures: use of the Kirchoff equation

*Feasibility*: Gibbs energy; condition of a negative change in Gibbs energy for a feasible reaction; significance of the signs of $\Delta H$ and $\Delta S$; $\Delta G^{\theta} = \Delta H^{\theta} - T\Delta S^{\theta}$; assumptions made; relationship to equilibrium constants

*Changes in enthalpy, entropy, and Gibbs energy*: any reaction for which two of these changes may be used to determine the third eg for metal/metal salt displacement where $\Delta H$ may be found from temperature measurements and $\Delta G$ from the appropriate electrochemical cell

2 **Understand the use of rate equations to determine the order of a reaction**

*Methods for following rate of reaction*: methods eg spectrophotometry, conductivity, optical rotation, refractive index, dilatometry, measurement of gas pressure, titrimetry of aliquots, problems of fast reactions

*Integrated rate equations*: zero, first and second order reactions (integration of rate expressions is desirable but not mandatory); units of rate constant; half-life expressions; percentage reaction

*Methods for finding reaction order*: minimum of two eg plotting graphs of functions of concentration versus time in accordance with the integrated rate expressions, use of the general half-life expression for an nth order reaction, use of gradients of two tangents (d[A]/dt) to the reactant concentration versus time plot at concentrations, $[A]_1$ and $[A]_2$ , using the method of initial rates for systems involving more than one reactant

*Basis*: theoretical explanations; relevant equations; assumptions

*Determining reaction order from data*: a method based on experimental data eg ester hydrolysis, hydrolysis of sucrose, reaction of diazonium salts with water, reaction of crystal violet with hydroxide, iodide/persulfate; tables of concentration/time data

3 **Understand ionic conductance**

*Terms and units commonly used*: resistance (Ω); conductance ($\Omega^{-1}$, S, mS, μS); cell constant ($m^{-1}$, $cm^{-1}$), conductivity ($\Omega^{-1}\ m^{-1}$, $\Omega^{-1}\ cm^{-1}$, S $m^{-1}$, S $cm^{-1}$, mS $cm^{-1}$, μS $cm^{-1}$ etc), concentration (mol $dm^{-3}$, mol $m^{-3}$, mol $cm^{-3}$), molar conductivity, Λ, (S $m^2$ $mol^{-1}$, $\Omega^{-1}$ $m^2$ $mol^{-1}$, S $cm^2$ $mol^{-1}$, $\Omega^{-1}$ $cm^2$ $mol^{-1}$), limiting molar conductivity, $\Lambda^{\theta}$, ionic mobility ($m^2$ $s^{-1}$ $V^{-1}$ , $cm^2$ $s^{-1}$ $V^{-1}$), ionic charge (C $mol^{-1}$)

*Constants*: shape of molar conductivity versus square root of concentration for weak electrolytes; limiting molar conductivity for strong electrolytes from extrapolation of plot of molar conductivity versus square root of concentration plots; limiting molar conductivity for weak electrolytes from molar conductivities of individual ions; discussion of values of limiting molar conductivities of individual ions with reference to their charge and mobility; acid dissociation constant; solubility; solubility product; assumptions inherent in calculations

*Conductivity titrations*: strong acid/strong base titration; one other type of titration eg weak acid/strong base, strong acid/weak base, weak acid/weak base and precipitation

*Conductance experiments*: explanation of specific calibration procedures for instruments used; determination of cell constant; variation of molar conductivity with square root of concentration for a strong and a weak electrolyte; determination of acid dissociation constant; determination of solubility product

4 **Understand the application of principles of oxidation and reduction to electrochemical systems**

*Standard cell voltage, $E^{\theta}_{cell}$*: oxidation and reduction equations for half-cells; overall cell reaction (redox equation); experimental set-up; redox reactions involving metal/metal ion and platinum/redox couple; use of tables of standard reduction potential to calculate theoretical values of $E^{\theta}_{cell}$; positive standard cell potential, $E^{\theta}_{cell}$ for a feasible cell reaction; pictorial representation of apparatus showing electron flow; IUPAC standard cell notation; reference electrodes eg standard hydrogen, calomel, silver/silver chloride; liquid junction; salt-bridges; experimental determination of cell voltage for simple cells involving metal/metal ion couple or platimum/redox couple half cells; possible reasons for differences between measured and calculated values eg use of concentration rather than activity, liquid junction potential, differences in temperature; $\Delta G = -nFE$ and $\Delta G^{\theta} = -nFE^{\theta}$

*Nernst equation*: relationship between activity and concentration; $E_{cell} = E^{\theta}_{cell} – (RT/nF) \ln Q$ where Q is the product of product activities divided by the product of reactant activities (raised to the powers of the stoichiometric numbers where applicable) for the cell reaction; ability to write a Nernst equation formula for a range of cells; ability to calculate a value for $E_{cell}$ given the half-cells involved, temperature and the activity of relevant ions

*Electrolysis*: molten salts; aqueous solutions of ions, the role of water; overvoltage; oxidation and reduction equations; products at anode and cathode

*Use of Faraday's law*: one Faraday equivalent to one mole of electrons flowing in an electrolysis cell; one Faraday = 96485 C $mol^{-1}$; current = charge/time; calculation of mass of metal plated on cathode given current and time; volume of gas collected at 1 bar pressure and a temperature of 298K in a given electrolysis cell

*Commercial applications*: electrolytic processes eg chlor-alkali industry, Downs cell, Diaphragm cell, membrane cell, Hall-Heroult process, electrorefining, electroplating

## Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the application of the first, second and third laws of thermodynamics to predict the feasibility of reactions | 1.1 define a range of standard changes in enthalpy<br>1.2 calculate changes in entropy<br>1.3 apply thermodynamic data to calculate standard changes in enthalpy and entropy for given reactions<br>1.4 calculate enthalpy changes at different temperatures<br>1.5 predict the feasibility of given reactions<br>1.6 experimentally determine changes in enthalpy, entropy, Gibbs energy, using safe practices |
| LO2 Understand the use of rate equations to determine the order of a reaction | 2.1 review methods for following rate of reaction<br>2.2 apply calculations using the integrated rate equations<br>2.3 explain the basis for two methods for determination of reaction order<br>2.4 use appropriate methods to determine reaction order from data |
| LO3 Understand ionic conductance | 3.1 explain, using appropriate units, terms commonly used in the measurement of electrolytic conductance<br>3.2 calculate, using conductance measurements, constants for strong and weak electrolytes<br>3.3 explain the shape of plots from conductivity titrations<br>3.4 perform appropriate conductance experiments, using safe practices |
| LO4 Understand the application of principles of oxidation and reduction to electrochemical systems | 4.1 explain reasons for differences between theoretical and experimental values for standard cell voltage, $E^{\theta}_{cell.}$<br>4.2 apply the Nernst equation to calculate electrochemical cell potentials at activities other than unity<br>4.3 apply Faraday's law to calculate amounts of product in given electrolysis cells<br>4.4 discuss commercial uses of electrolysis which illustrates the underlying chemical principles |



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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 2: Organic Chemistry*
- *Unit 4: Chemical Laboratory Techniques*
- *Unit 9: Inorganic Chemistry of Crystal Structures and Transition Metal Complexes*
- *Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds*
- *Unit 11: Physical Chemistry of Spectroscopy, Surfaces and Chemical and Phase Equilibria*
- *Unit 12: Analytical Chemistry*.

## Essential requirements

## Delivery

This unit contains a great deal of formal notation and a wide range of quantities and their correct units. An active and experimental approach must be adopted to demonstrate the relevance of the topics to the vocational setting. Tutors must stress the applications of the topics to the chemical process industry and to analytical chemistry.

Tables of thermodynamic data must be used extensively in learning outcome 1. It is envisaged that much of the delivery of this unit will involve building learners' confidence in performing calculations.

Producing an account of methods used in measuring reaction rate should be based on experiments or demonstrations that learners have experienced, for example measuring the volume/pressure of a carbon dioxide in the reaction between calcium carbonate and acid, following the absorbance of a solution of crystal violet and sodium hydroxide, measuring the pH of an acid hydrolysis reaction. Many learners will not have the mathematical background to follow the integration of the differential rate equations. It is then optional whether to integrate the equations or not. However, learners must be able to use the integrated forms of the rate equations to calculate concentrations, reaction times, half-lives and % reaction.

The methods for finding reaction order should be chosen to reflect the mathematical ability of learners. Appropriate equations and manipulations must be used as part of their explanation for why the methods work.

A minimum of two methods for finding reaction order must be used.

The use of conductance symbols and units is difficult for learners to grasp. Learners should build up a glossary of terms and units throughout the delivery of this unit. Experiments which may be carried out include the measurement of conductivity of strong and weak electrolytes (such as potassium sulfate and ethanoic acid) as a function of concentration and the square root of concentration. This introduces the concept of limiting molar conductivity. Learners will appreciate that this may be measured for strong electrolytes but not for weak electrolytes. Learners may calculate the limiting molar conductivity from tables of the limiting molar conductivity of the separate ions involved. The role of mobility and concentration in determining conductivity must be explained. The measurement of conductivity of water samples is used extensively in industry as a measure of the purity of water.

Learners should be familiar with the calculation of standard cell potential. The concepts of half-cell, oxidation, reduction, overall cell reaction, construction of relevant equations, possible experimental set-ups, standard reduction potential, standard conditions and calculation of standard cell potentials must be revised and the concepts of activity, liquid junction and liquid junction potential introduced. Learners must measure cell voltages for simple cells. Appropriate half-cells are $Zn^{2+}/Zn$, $Pb^{2+}/Pg$, $Cu^{2+}/Cu$. Half-cells involving platinum and two ions in solution, eg $Fe^{3+}$, $Fe^{2+}/Pt$ may be used if appropriate. Learners must calculate expected voltages, measure voltages, compare values obtained and suggest reasons for differences.

Learners need to predict products of electrolysis from simple, aqueous ionic solutions and molten ionic substances. They need to write oxidation and reduction equations.

Electrolysis is important industrially. If possible, learners should visit a site where electrolysis takes place to appreciate the scale of the industrial process and the potential environmental implications. There are CD clips that illustrate the processes that use electrolysis.

## Assessment

Learning outcome 1 will mainly be assessed through performing a range of straightforward calculations successfully. At least one experiment, relating changes in enthalpy, entropy and Gibb’s energy must be carried out.

For learning outcome 2, learners must review a minimum of three methods for following rate of reaction. The methods of finding reaction order must be tailored to learner ability. At least two data-handling exercises must be used for finding the order of reaction. Two different methods of finding order must be used. At least one experiment should be involved.

Learning outcome 3 is easily assessed through learners making a glossary of terms and performing the indicated conductivity measurements and manipulating the data appropriately.

For learning outcome 4, learners must measure voltages of appropriate electrochemical cells and compare these with calculated values, suggesting reasons for differences. Several Nernst equations must be constructed and at least two evaluated, given appropriate data.

## Resources

Learners will need access to appropriate laboratory facilities and technical support.

## Employer engagement and vocational contexts

Learners should have the opportunity to observe a commercial electrolytic process in action. Industrial representatives could give presentations on the relevance to process control of thermodynamics and rate of reaction. The industrial relevance of conductivity measurement to the pharmaceutical sector and in environmental management should be addressed. The Nernst equation in relation to biological processes, to electrolysis and to corrosion should be considered.

# Unit 4: Chemical Laboratory Techniques

Unit code: H/601/0355

Level: 4

Credit value: 15

## Aim

This unit gives learners the opportunity to practise and become proficient in a range of practical skills and data analysis commonly used in analytical and preparative chemistry.

## Unit abstract

Science learners need to acquire a breadth and depth of practical skills in order to become proficient at experimental work across the range of disciplines embraced by the subject of chemistry. In this unit learners will become familiar with titrimetric, spectroscopic and chromatographic techniques in addition to techniques needed to prepare pure samples of compounds. They will also develop the ability to present experimental results in a variety of formats and to write different styles of report. Learners will also learn how to assess the risks associated with particular practical techniques.

On completion of the unit, learners should have developed the flexibility to use unfamiliar techniques by following given instructions and be able to report on and assess the reliability of the techniques.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to use a range of techniques in the synthesis of substances

2 Be able to use spectroscopic techniques

3 Be able to use chromatographic techniques

4 Be able to use titrimetric techniques.

# Unit content

1 **Be able to use a range of techniques in the synthesis of substances**

*Minimising risks*: hazards associated with chemicals eg flammable, toxic, harmful; other hazards eg high temperatures, use of glass equipment; risk minimisation eg use of alternative substances, reduction of quantities, selection of method of heating, selection of location, use of fume cupboard, wearing gloves, lab coat, safety glasses, methods for handling hot objects

*Preparative techniques*: common procedures eg vacuum filtration, recrystallisation, simple distillation, fractional distillation, vacuum distillation, steam distillation, rotary evaporation, solvent extraction, drying

*Substances*: solid organic compounds eg DNP and semicarbizone derivatives, aspirin, paracetamol, antifebrin; a liquid organic compound eg ethyl ethanoate, cyclohexene, heptene; inorganic compounds eg complexes of copper or nickel, tin (IV) iodide, organometallic compounds such as 1,1 - diacetylferrocene

*Tests to determine purity*: melting points; boiling points eg Siwoloboff's method and simple distillation; spectroscopic techniques eg infrared spectroscopy, ultraviolet/visible spectroscopy; chromatographic techniques eg thin layer chromatography

*Yields*: theoretical and percentage yields

*Report*: formal laboratory report; other methods of reporting eg completion of a proforma, preparation of a PowerPoint presentation, making a poster, writing an article

2 **Be able to use spectroscopic techniques**

*Guidelines*: format eg instruction sheets, verbal instructions, instruction manuals

*Spectroscopic techniques*: infrared (IR) spectroscopy; ultraviolet (UV) spectroscopy; visible (Vis) spectroscopy; other techniques eg flame emission, atomic absorption (AA), nuclear magnetic resonance spectroscopy (NMR), mass spectroscopy (MS), x-ray fluorescence (XRF)

*Analyses*: use of spectra to determine purity; use of Beer-Lambert Law to determine concentrations of solutions

*Appropriate degree of accuracy*: in quantitative determinations eg comparison with reference value with given tolerance, use of class results/statistical treatments to establish appropriate tolerance

*Present*: format eg poster, documented verbal account including use of diagrams, part of a report, separate written account, PowerPoint presentation slides, verbal presentation

*Principles behind techniques*: component representation using block diagrams eg source of radiation, means of wavelength selection, nature of sample, sample container, detection method, scanning, fixed wavelength applications; Beer-Lambert Law; range of standard solutions; calibration graph; methods of calculation of unknown concentrations

*Report*: formal laboratory report; other methods of reporting eg completion of a pro forma, preparation of a PowerPoint presentation, making a poster, writing an article

3 **Be able to use chromatographic techniques**

*Assess the risks*: formal risk assessment for thin layer chromatography (TLC) involving a liquid mobile phase and a locating agent; formal risk assessment for an instrumental technique

*Chromatographic separations*: TLC; column chromatography; other techniques as available eg gas chromatography (GC), high performance liquid chromatography (HPLC), electrophoresis, ion-exchange; use of locating agents eg iodine, ninhydrin, cerium sulfate

*Quantitative techniques*: interpretation of results from GC; HPLC; integration of peak area; composition of a mixture or concentration of a solution

*Present*: format eg poster, documented verbal account including use of diagrams, part of a report, separate written account, PowerPoint presentation slides, verbal presentation

*Principles*: mobile phase eg solvent, carrier gas; stationary phase eg water within paper, silica, viscous liquid on GC capillary/support; sorption mechanism eg adsorption, partition, ion-exchange; column eg GC, HPLC, ion-exchange; layer eg paper and thin layer; detection of components eg colour of components, locating agent, flame ionisation detector (FID), absorption of ultraviolet light; calculation of $R_f$ values; retention time; features of specific techniques eg oven in GC, pump and degassing of solvents in HPLC; block diagrams of instrumental techniques

*Report*: formal laboratory report; other methods of reporting eg completion of a pro forma, preparation of a PowerPoint presentation, making a poster, writing an article

4 **Be able to use titrimetric techniques**

*Quantitative methods*: balances eg top pan, analytical; volumetric equipment eg automated pipettes, syringes, burettes, volumetric flasks; use of primary standard solutions; dilution techniques

*Range of titrimetric methods*: acid-base; redox eg use of potassium manganate (VII), thiosulfate/iodine; complexometric eg use of ethylene diamine tetra-acetic acid (EDTA) to determine $Cu^{2+}$ concentration; precipitation eg titration of chloride with silver nitrate; potentiometry eg use of a pH electrode; indicators; forward titrations; backward titrations

*Identify the risks*: formal risk assessment for a titrimetric procedure; identify aspects of given procedures which minimise the inherent risks

*Report*: formal laboratory report; other methods of reporting eg completion of a pro forma, preparation of a PowerPoint presentation, making a poster, writing an article

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to use a range of techniques in the synthesis of substances | 1.1 assess the risks inherent in syntheses<br>1.2 demonstrate competence in a range of preparative techniques, using safe practices<br>1.3 perform appropriate tests to determine the purity of synthesised substances<br>1.4 determine the yield of compounds prepared<br>1.5 report on the syntheses |
| LO2 Be able to use spectroscopic techniques | 2.1 prepare and calibrate instruments for use following given guidelines<br>2.2 perform analyses using spectroscopic techniques to an appropriate degree of accuracy, using safe practices<br>2.3 explain the principles behind the techniques used<br>2.4 report on the analyses |
| LO3 Be able to use chromatographic techniques | 3.1 assess the risks and carry out chromatographic separations, using safe practices<br>3.2 use results from chromatographic techniques quantitatively<br>3.3 explain the principles of chromatography<br>3.4 report on analyses that use chromatography |
| LO4 Be able to use titrimetric techniques | 4.1 identify the risks associated with titrimetric procedures<br>4.2 routinely and accurately use equipment to prepare solutions using quantitative methods<br>4.3 use a range of titrimetric methods to determine the concentrations of solutions, using safe practices<br>4.4 report on the titrations |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 2: Organic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 9: Inorganic Chemistry of Crystal Structures and Transition Metal Complexes*
- *Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds*
- *Unit 11: Physical Chemistry of Spectroscopy, Surfaces and Chemical and Phase Equilibria*
- *Unit 12: Analytical Chemistry*.

## Essential requirements

## Delivery

The unit must be delivered through a well-planned programme of practical work. Learners must learn about chemical and non-chemical hazards, and be able to identify how given procedures minimise the risks associated with hazards. Learners must learn how to undertake a risk assessment of a procedure and use the correct risk and safety terminology.

The centre should select the most appropriate synthetic techniques to use. Learners must prepare two organic solids. One could be a derivative, such as a dinitrophenyl hydrazone or semi-carbizone derivative of an aldehyde or ketone. The other should be a compound other than a derivative. Learners must prepare one organic liquid and two inorganic solids. These could be transition metal complexes or organometallic compounds. In selecting the syntheses, learners must have the opportunity to use TLC to follow the progress of one of the syntheses. Learners should use chromatographic, spectroscopic and titrimetric methods to estimate the purity of the compounds made, in addition to melting point and boiling point measurements. Yield must be measured for each compound prepared.

Learners must be able to use scanning infrared and ultraviolet/visible spectroscopy and relate the spectra to the structure and bonding of the compounds. Learners should also use fixed wavelength applications, based on the Beer-Lambert Law to determine concentrations. Learners need access to Excel spreadsheets to construct calibration graphs and use the equation of the calibration graphs to calculate the unknown concentrations.

Learners must be able to use column chromatography and thin layer chromatography.

Learners require access to infrared and ultraviolet visible spectrometers, gas chromatographs and high performance liquid chromatographs. Where centres do not have these instruments visits should be arranged for learners to use the spectroscopic techniques and see the chromatographic techniques in action. Learners should be given chromatograms to interpret. Learners must be able to use, or observe the use of, as many spectroscopic techniques as possible. The operation of instruments in relation to block diagrams should be explained.

Learners must learn how to identify components of chromatograms from GC and HPLC in relation to retention time. The integration of the area under the peaks should be introduced as a quantitative measure.

## Assessment

Producing a formal report for each synthetic or analytical procedure is likely to be too time consuming. A limited number of formal reports should be produced (see below). Learners should present the results from their work in a variety of ways eg using formal presentations, completion of pro formas, construction of posters and articles. Emphasis must be on recording and reporting all results, calculations and conclusions in an appropriate format.

In identifying how the risks inherent in syntheses may be minimised, learners must identify the chemical and non-chemical hazards for at least two syntheses. Learners need to record ways of minimising the risks from these hazards which they could do by producing a formal risk assessment for the two syntheses.

Learners must undertake five preparatory techniques ie, two organic solids, one organic liquid and two inorganic or organometallic compounds.

Learners must measure melting points of solid compounds prepared and boiling points of the liquids prepared and interpret the results from these tests as part of the reporting of results. Depending on the facilities of the centre, learners should perform additional tests to determine the purity of substances prepared and report on the results. As part of the reporting of results, there must be a calculation of the % yield of substance prepared, based on the number of moles expected and actually produced. Learners must produce one formal report on a synthesis carried out.

Analyses using spectroscopic techniques could be qualitative or quantitative. Learners could carry out qualitative analysis in relation to synthetic techniques. Qualitative spectroscopy may simply involve identification of the functional groups present in a sample and matching spectra of unknown compounds with those of known compounds. Quantitative spectroscopy involves use of the Beer-Lambert Law. Learners could either use a given method or develop a method where standards of known concentration are made and used to find the concentration of a sample at a fixed wavelength. A colorimeter could be used for this if the centre does not have regular access to a visible spectrometer.

Learners must produce one formal report for a spectroscopic technique. This must include a description of the underlying principles and a consideration of the reliability of results. Each technique used must be reported using an appropriate format, for example by a pro forma or producing a report. Where a pro forma is used for calculations and consideration of the reliability of results, learners must produce an additional account of the principles of the technique. It is up to the centre to ensure that learners carry this out in a meaningful way.

Learners must be observed carrying out competent separations using column chromatography and thin layer chromatography. Since many such separations involve mobile phases and possibly locating agents with significant chemical hazards, learners must carry out at least one recorded formal risk assessment for such a procedure and one risk assessment for an instrumental procedure.

Learners could carry out GC and HPLC quantitatively or be given results to interpret. They must produce at least one formal report for a chromatographic technique including the principles of the technique. The results and conclusions from the other techniques may be presented as a report, pro forma, presentation or other document.

There must be a record of the titrimetric procedures that learners have carried out. When reporting on titrations, learners must consider the reliability of the results obtained. They must produce at least one formal report on a titrimetric technique and one formal risk assessment for a titrimetric procedure. Learners need to show evidence of considering the risks associated with other procedures.

## Resources

Access to practical laboratory facilities, technical support, library facilities and IT resources are essential.

Royal Society of Chemistry online access to sites such as: Chemistry Hazards in Industry and the Analytical Cookbook database.

## Employer engagement and vocational contexts

Where learners work in the chemical industry, discussion about the use of techniques should be encouraged. For full time learners visits should be arranged to local industry and to local higher education institutions to see the techniques in action. Guidance on assessment may be contextualised with reference to techniques used routinely in local industry.

# Unit 5: Project for Applied Science

Unit code: J/601/0221

Level: 5

Credit value: 20

## Aim

This unit enables learners to integrate acquired knowledge, understanding and skills and display a significant degree of autonomy applying them in an individual practically-based study.

## Unit abstract

Development of knowledge and skills within higher level qualifications is sometimes limited by the modular structure of the programme. In employment, however, learners are frequently required to use knowledge and skills across a range of subject disciplines and apply them in unfamiliar situations. It is essential therefore that they are able to apply planning, research and analytical skills, in addition to being able to identify, access and use a variety of information sources. They must work safely and accurately, keep detailed records and process information and data precisely, as well as communicating their results in a variety of ways suited to a target audience.

The project topic can be drawn from a wide variety of activities appropriate to the programme of study but learners must be actively involved in the selection and development of the project proposal. Learners must take responsibility for producing a project plan that should be agreed with the assessor. The work should be carried out logically, based on the application of scientific method. The results of the investigation should be evaluated and presented in the form of a scientific report.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to plan a project

2 Be able to implement the project plan

3 Be able to evaluate the project outcomes

4 Be able to communicate the project investigation and its results.

# Unit content

1 **Be able to plan a project**

*Project specification*: practical and literature based; scope and purpose of the investigation; intended outcomes; methods of approach; resource requirements

*Review key information*: background theory; supporting data; published methods; identification and acquisition of sources; use of texts, journals and internet

*Experimental design*: standard published methods; reported alternative procedures; existing equipment and materials; sources and access to other equipment; achievable timescales; criteria for success; identified monitoring points and procedures

*Amend schedule*: agreed amendments relating to project specification, timescales etc following discussions with supervisor

2 **Be able to implement the project plan**

*Investigation*: experimental work; operating methods and procedures; acquisition of equipment and materials; methods of data collection and recording; accuracy and precision; quality standards; minimisation of errors; use of statistical techniques

*Safety*: potential hazards eg risk assessment, COSHH analysis

*Logbook*: dated entries; tables and records of results; correct use of units; error analysis; own versus group results; schedule amendment eg significant or unexpected events, deviations from expected data and results, progress made relative to original plan; agree proposed amendments

3 **Be able to evaluate the project outcomes**

*Analyse*: analysis of data and experimental observations; draw conclusions based on analysis of results

*Evaluate the study*: appropriate evaluation methods set against formulated criteria for success; use of correct statistical techniques; identification of sources of error; confidence limits for results

*Further investigations*: suggestions for further study relating to minimising errors; extending topic area; confirming or supporting conclusions

*Conclusions*: conclusions from analysis of data and experimental observations justified in terms of original specifications

4 **Be able to communicate the project investigation and its results**

*Scientific report*: abstract; introduction and objectives; literature survey; fully processed results (raw data; spectra etc may be included as an appendix); experimental work; critical discussion; suggestions for further investigation; appendices; bibliography

*Format*: conform to accepted scientific format relating to abstract; literature survey; tabulated results; in-text referencing and bibliography; written in third person past tense; use of spreadsheets, presentation packages and scientific software as appropriate

*Project specification:* practical and literature based; scope and purpose of the investigation; intended outcomes; methods of approach; resource requirements

*Presentation:* appropriate media; delivery suited to target audience; clear explanations of scope and results; justify conclusions

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to plan a project | 1.1 establish a project specification from consideration of the scope and purpose of an appropriate topic<br>1.2 undertake a review of key information that supports the work<br>1.3 produce an experimental design for the study<br>1.4 amend the schedule as appropriate following discussions with supervisor |
| LO2 Be able to implement the project plan | 2.1 record all safety requirements<br>2.2 undertake the investigation according to the agreed specification and safety codes of practice<br>2.3 compile a logbook documenting all observations and results |
| LO3 Be able to evaluate the project outcomes | 3.1 analyse results in terms of original specifications<br>3.2 use appropriate methodology to evaluate the study<br>3.3 propose areas of further investigation that could lead to improvement of the project outcomes<br>3.4 justify both the conclusions drawn from the study and the proposals for further investigation |
| LO4 Be able to communicate the project investigation and its results | 4.1 produce a scientific report in an accepted format<br>4.2 identify the extent to which the project specification has been met<br>4.3 prepare a presentation summarising the project investigation |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 4: Chemical Laboratory Techniques*
- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 7: Laboratory Management*
- *Unit 8: Work-based Investigation*
- *Unit 12: Analytical Chemistry*
- *Unit 22: Management of Projects*
- *Unit 27: Statistics for Experimental Design*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

### Delivery

This unit differs from *Unit 8: Work-based Investigation* in that the latter must be carried out in the workplace and gives credit for work-based activity. The *Project for Applied Science* unit is developed and planned within the centre of learning but some or exceptionally all of the practical work could be carried out in the workplace or elsewhere if that is where any specialist equipment is located. This unit requires coverage of broader topics and a greater learner input into topic selection, development and evaluation than is required for Unit 8. The work used for this unit must not be used for *Unit 8: Work-based Investigation*.

The project topic can be drawn from a wide range of activities appropriate to the programme of study but must have a significant practical investigation. It may be carried out individually or as a component of a team investigation. Where teamwork is involved sufficient documentation must be kept to demonstrate the individual efforts of each learner. Logbooks must distinguish clearly between team results and observations and work undertaken by the individual. Learners must display a significant amount of autonomy and apply their initiative and judgement in the selection and development of the project topic together with its execution and evaluation.

To ensure safe work practices, learners must be briefed thoroughly on project work methodology. All project specifications and schedules must be scrutinised and agreed by supervisors before learners start work and regular meetings between learners and supervisors should be scheduled to monitor progress. This support should not prevent learners from achieving the higher grades providing individuals make a significant contribution to the development of the plan, and their suggestions and actions are reasonable within their level of experience. Supervisor support should be available at all times during the project and detailed records kept of the extent of the support individuals required. This information should be used in making decisions on grading. Learners must be allowed to make their own decisions during the implementation phase and supervisors should normally intervene only when safety is likely to be compromised. A lot can be learned from negative results and failed experiments. Supervisors should not attempt to prevent this providing the learner's actions and decisions are reasonable and fall within the agreed plan. Results and achievements must be evaluated against the aims and criteria in the project plan.

## Assessment

Projects may be carried out individually or in small teams. In the case of team projects the supervisor must document individual contributions in sufficient detail to enable accurate grading and verification to take place. The interaction of team members should be considered, along with learner autonomy in completing the project, when looking at higher grading.

In all cases, planning for learning outcome 1 must be completed and agreed before learners start their practical work. The supervisor should also receive a draft report of the literature review and experimental design before the discussion stage in learning outcome 1. For learning outcomes 2 and 3, the supervisor needs to monitor the early stages of the work and the logbook and, providing learners are competent in safe working practices, progressively reduce the amount of supervision relating to the direction and management of the project.

The format of the final report for learning outcome 4 must be determined at the planning stage. Supervisors should set a deadline to see a draft version of the early sections (not the whole report), and provide feedback. Amendment and completion of the final scientific report should then take place without further assistance or comment from the supervisor. The presentation must be made to supervisors and fellow learners and may or may not include peer assessment. If the presentation is to be used to meet the higher grading criteria then minimum guidance should be given.

## Resources

This project unit will be developed and planned within the centre but some, or exceptionally all, of the practical work could be carried out in the workplace or elsewhere if this is where any essential specialist equipment can be located. Required resources will vary significantly with the nature of the project. The identification of equipment and materials, and establishment of their availability, is a vital part of the planning phase.

Tutors should ensure that learners do not start work that cannot succeed because of lack of access to the required resources. Use of specialised equipment outside the centre is acceptable, however, agreement on access must be reached before work begins. Learners will require access to computer and appropriate software packages in order to produce their report.

### Employer engagement and vocational contexts

Ideally, the project topic should have a vocational context. Where this is the case learners will benefit from visits to related industries to observe industrial aspects of their study area. In particular, where analytical procedures form a significant part of the project, a visit to a local company or hospital to see automated analytical procedures in action would be advantageous.

# Unit 6: Analysis of Scientific Data and Information

Unit code: F/601/0220

Level: 4

Credit value: 15

## Aim

This unit develops skills in mathematical and statistical techniques used in the analysis of scientific data, together with an understanding of the limitations in reporting results.

## Unit abstract

In the 21st century, a considerable amount of data analysis is performed by computers. The importance of understanding how and in what circumstances to use individual mathematical and statistical techniques, and the significance of the results, is not diminished by the availability of computational facilities. The primary outcome of scientific experimentation frequently comprises data, the volume of which varies significantly depending on the type of work undertaken. Analysis of the data which is obtained needs to be processed in some way to extract meaning.

This unit aims to develop previous knowledge and understanding gained in learning about scientific data analysis and extend it to a level appropriate for use in industry and research. Starting with the fundamental procedures of displaying information and data to standards expected in the field of science, the majority of the unit focuses on the use of mathematical and statistical techniques in appropriate contexts. Treatment of these techniques is practical rather than theoretical.

Learners will examine how the outcomes of processing are used, in terms of values generated and their associated errors, to generate valid conclusions.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to present information and data to scientific standards

2 Be able to process data using numerical analysis

3 Be able to process data using statistics

4 Understand limitations in concluding results.

# Unit content

1 **Be able to present information and data to scientific standards**

*Presentation of information*: target audience; fitness for purpose of media used; clarity of information; communication of work carried out

*Display data*: tabulation; bar charts; pie charts; frequency polygons; ogives; histograms; scatter diagrams

*Graphical methods*: linear axes; non-linear axes eg logarithmic, exponential; curve fitting; linear regression eg least squares method

2 **Be able to process data using numerical analysis**

*Algebraic methods*: transposing equations; linear equations; simultaneous linear equations; quadratic equations; roots of quadratic equations

*Use of calculus*: standard differentiation; first order derivatives of equations; applications of differential equations eg reaction rates; standard integration; definite integration; application of definite integration eg area under a curve

*Errors in data*: classification of sources of errors eg random, systematic, gross; difference between accuracy and precision; handling errors in data processing eg absolute, relative, compound

3 **Be able to process data using statistics**

*Descriptive statistics*: measures of central tendency eg mode, median, mean; measures of dispersion eg variance, standard deviation; coefficient of variation

*Normal distributions*: probability distributions; normal distributions; standardising; tests for normality; percentiles; samples of populations; standard error of the mean; confidence limits

*Hypothesis testing*: null hypothesis; alternative hypothesis

*Statistical tests*: type eg z-test, student's t-test, F-test, Pearson's chi-squared ($\chi^2$) test, Pearson's product moment correlation coefficient; significance levels; power of the test; one-tailed and two-tailed

4 **Understand limitations in concluding results**

*Total error in results*: combination of component errors; representation of numbers; round-off errors; truncation errors; level of confidence in results obtained

*Conclusions from the work*: values of measured parameters; validity of hypotheses; support for theoretical models; confirmation of model developed; accuracy; precision of measurements

*Information on the problem studied*: fitness for purpose of the methods used; validity of conclusions; information provided on the systems studied; compatibility of results with those from other sources

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to present information and data to scientific standards | 1.1 create a plan for the presentation of scientific information<br>1.2 display data to scientific standards using planned methods<br>1.3 carry out graphical methods of displaying scientific data |
| LO2 Be able to process data using numerical analysis | 2.1 perform numerical analysis on scientific data using an algebraic method<br>2.2 demonstrate numerical analysis using calculus on standard polynomial equations<br>2.3 evaluate absolute errors in scientific data |
| LO3 Be able to process data using statistics | 3.1 perform descriptive statistics on a sample of continuous scientific data<br>3.2 demonstrate the nature of normal distributions using a sample of continuous scientific data<br>3.3 carry out hypothesis testing using standard statistical tests and draw conclusions |
| LO4 Understand limitations in concluding results | 4.1 evaluate the total error in a sample of continuous scientific data<br>4.2 assess the accuracy of a model using the outcomes of processing carried out on experimental data<br>4.3 justify the validity of conclusion(s) from the information on a problem studied |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 5: Project for Applied Science*
- *Unit 8: Work-based Investigation*
- *Unit 27: Statistics for Experimental Design*.

## Essential requirements

## Delivery

Delivery must focus on the application of mathematical or statistical techniques in science, rather than on the techniques themselves. Emphasis must be on the selection and implementation of methods appropriate to given scientific contexts, and on the evaluation of the significance of the results and conclusions obtained. Delivery must draw on data from experimental units within the programme of study and use experiments as models for design and analysis. Learners must be taught to use software correctly, and to appreciate both the strengths and limitations of the methods used.

Delivery teams should analyse the mathematical requirements of their programmes and select the set of techniques learners will need to derive meaning from the information and data they will encounter during their studies.

## Assessment

Learning outcome 1 involves presenting information and data to standards expected in the science industry.

Learning outcomes 2 and 3 involve the mathematical and statistical techniques commonly used in the process of scientific data analysis. Emphasis must be on the accurate application of the methods covered, rather than on demonstrating understanding of the mathematical concepts. Evidence should include case studies or experimental studies, where appropriate.

Learning outcome 4 involves the generation of a formal conclusion based on the outcome of the data analysis. Evidence may be integrated with evidence from the other three learning outcomes.

## Resources

Learners will need access to IT facilities and appropriate software to enable them to tackle realistic problems. Many of the operations relevant to applied science programmes can be implemented using a generic spreadsheet package (such as Microsoft Excel). Ideally, this will be supplemented by dedicated mathematical or statistical packages for example Minitab, PASW Statistics or MATLAB.

## Employer engagement and vocational contexts

Learners will benefit from visits to industrial and research facilities to observe practical applications of data analysis, or to gain access to learning materials.

# Unit 7: Laboratory Management

Unit code: L/601/0222

Level: 4

Credit value: 15

## Aim

This unit enables learners to gain an understanding of the organisation of different types of laboratory and compare the processes associated with their management.

## Unit abstract

Many learners studying at this level will either have supervisory duties or may move into such a role in the future. This unit examines typical responsibilities of laboratory managers. Types of laboratories considered include contract analytical laboratories, project laboratories supporting innovation in and efficiency of a manufacturing process, quality control laboratories associated with manufacturing, and educational laboratories.

Management roles within these laboratories vary widely. With contract analysis, the emphasis is on providing accurate, accredited and legally defensible results. Project laboratories may carry out pilot studies on how products or production processes may be altered. By focusing on quality control they ensure that products made and supplied have properties within the tolerances specified by the customer. They may also test raw materials to ensure that they are processed into products of the correct quality. Laboratories in education may support learning or have a research focus, as in many universities. All laboratory managers need to ensure that their staff are trained appropriately and understand the tasks they have to perform. They have to ensure that the laboratory is fully resourced and that due regard is given to health and safety. They are also likely to have specific skills, for example expertise in carrying out particular procedures correctly, the ability to work to a project brief and knowledge of statistics and systems.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the typical duties of laboratory managers in different types of laboratory

2 Understand aspects of laboratory organisation

3 Understand how laboratories comply with health and safety legislation

4 Understand features of managing a quality system.

# Unit content

1 **Understand the typical duties of laboratory managers in different types of laboratory**

*Functions of a contract analytical laboratory*: production of high quality data; working for a client; low cost; accuracy; reproducibility; traceability; importance of booking in samples; barcoding; legally defensible data; part of an accreditation scheme; ability to respond to customer needs; assessing the quality of data; reporting and discussing results; examples of types of analysis performed by contract laboratories eg oil, food, forensic samples, medical samples, soil, water; possible duties of a laboratory manager in the context of a contract analytical laboratory

*Role of an industrial project laboratory*: product innovation; investigation of aspects of the operation of a manufacturing plant; producing materials on a pilot scale; project management; importance of timescale; deadlines depending on the project; record keeping – may be non-standard; reporting in a number of formats; possible duties of a laboratory manager in the context of an industrial project laboratory

*Role of a quality control laboratory*: sampling techniques; storage; testing raw materials; testing product; results within given tolerances for different grades of product; reporting results to production staff; testing product during production and after production; possible duties of a laboratory manager in the context of a quality control laboratory

*How an educational laboratory may differ*: less likely to use standard protocols/methods; may support research; may support learner's learning; fewer routine activities; possible duties of a laboratory manager in an educational laboratory in comparison to those of other laboratory managers

2 **Understand aspects of laboratory organisation**

*Sources of reference*: equipment manuals; staff training records; company policies; staff intranet; CLEAPSS material for school/college technicians

*Purchasing*: lists of approved suppliers; budget; internal order forms; ordering procedures; need for signatures on orders; approved suppliers; the need to obtain quotes

*Stock control systems*: inventories of chemicals and other consumables; equipment lists; receiving stock; checking stock; storing stock; stock rotation; stock taking; maintaining records; control of stationery; special storage eg refrigeration, vented storage

*Laboratory design*: purpose of laboratory; special features relating to purpose; space needed by individuals; water; gas; electricity; sinks; waste; safety features eg extraction, safety shower, solvent sink; lighting; sample entry; space occupied by equipment; areas for writing/use of computer; storage for eg glassware, chemicals, stationery, labels, waste, samples; work surfaces

3 **Understand how laboratories comply with health and safety legislation**

*Legislation*: Health and Safety at Work Act (1974); duties of employers; duties of employees

*Regulations:* eg the Management of Health and Safety at Work Regulations (1999), COSHH Regulations (2002), Workplace (Health, Safety and Welfare) Regulations (1992); approved codes of practice; guidance

*Responsibilities of laboratory managers*: management of health and safety eg provision/maintenance of safe systems of work, risk assessment, training, enforcing local laboratory rules, health and safety policy, first aid provision, accident/incident and near miss reporting, health and safety systems, audits, housekeeping

4 **Understand features of managing a quality system**

*Company policies*: functions eg health and safety, data management, reporting, customer service, training

*Standard operating procedures*: procedures eg testing; calibration, assessing data, reporting; consequences of not following standard procedures

*Staff training*: accreditation requirements; minimisation of random error; training record; being trained to approved standard; self-confidence; pride

*Data management*: unique sample numbers; sample entry; paper-based systems; computer-based systems; LIMS; back up; worksheets; hard back notebooks; signatures; initialling of errors; results; reports; traceability; training records; standard procedures; calibration records; inventories of equipment and materials; internal quality checks; external quality checks eg details of inter-laboratory testing, accreditation information and records

## Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the typical duties of laboratory managers in different types of laboratory | 1.1 explain how a laboratory manager may contribute to the functions of a contract analytical laboratory<br>1.2 explain how a laboratory manager supports the role of an industrial project laboratory<br>1.3 explain how a laboratory manager may facilitate the smooth running of a quality control laboratory<br>1.4 discuss how the role of an educational laboratory manager may differ from that of an industrial laboratory manager |
| LO2 Understand aspects of laboratory organisation | 2.1 evaluate commonly used sources of reference on laboratory management<br>2.2 investigate key areas for consideration when purchasing equipment and consumables<br>2.3 explain the operation of a stock control system<br>2.4 discuss features of laboratory design |
| LO3 Understand how laboratories comply with health and safety legislation | 3.1 explain the duties of employers and employees under the Health and Safety at Work Act (1974)<br>3.2 investigate regulations which are relevant to working in laboratories<br>3.3 explain typical responsibilities of a laboratory manager in terms of managing health and safety |
| LO4 Understand features of managing a quality system | 4.1 discuss the function of company policies<br>4.2 analyse the importance of following standard procedures<br>4.3 justify the need for staff training<br>4.4 review how data are managed in the laboratory |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 4: Chemical Laboratory Techniques*
- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 12: Analytical Chemistry*
- *Unit 21: Quality Assurance and Quality Control*
- *Unit 22: Management of Projects*
- *Unit 23: Managing the Work of Individuals and Teams*.

This unit also links with the following NOS:

NVQ L4 Laboratory and Associated Technical Activities (LATA).

**Essential requirements**

## Delivery

Literature on laboratory organisation and management is limited. The best resource is the experience of trained laboratory technicians and managers. Where learners are working in laboratories, they should discuss the different functions and roles of their laboratories. Learners who do not work in laboratories must have the opportunity to visit laboratories and/or talk to staff working in a range of laboratories. Where access to a range of laboratories is difficult to obtain, tutors could prepare case study material for learners to use. Learners must be encouraged to discuss features of laboratories that they know well and to evaluate whether the laboratory design is fit for purpose.

There are several excellent textbooks dealing with health and safety legislation. The Health and Safety Executive publishes many free leaflets. Learners must become familiar with the nature of health and safety legislation in general and then think of how it is applied to a laboratory. Again, there is scope for specialist input from health and safety managers and health and safety representatives.

Learning outcome 4 requires understanding of a quality system. Learners may use general information about quality systems and the use of standard procedures to support these systems.

## Assessment

For learning outcome 1, learners could research the work that different types of laboratories carry out. This would make use of visits and case studies. Learners can then explain typical duties of managers in each type of laboratory or explain duties common to all functions and analyse specific differences in roles.

For learning outcome 2, learners must make use of information from their workplace, visits, guest speakers and centre technicians. Learners could design an ideal laboratory or alternatively they could present a plan of a laboratory that they know and discuss its design and features.

Learners have more reference material to use in approaching learning outcome 3. More-able learners will be able to contextualise general information to the laboratory setting and to envisage the role of the laboratory manager.

For learning outcome 4, tutors should give learners a realistic scenario such as a picture of a failing laboratory and then for learners to explain how using a quality system would enable the laboratory to succeed.

## Resources

Case study material relating to a variety of laboratories is essential. Learners should have the opportunity to use the centre technicians as a resource. Library resources on health and safety are important as is access to the internet.

## Employer engagement and vocational contexts

Learners must engage with common practice used in industrial and educational laboratories. This could be through visits, guest speakers, case studies or discussion with other learners.

# Unit 8: Work-based Investigation

| | |
|---|---|
| Unit code: | R/601/0223 |
| Level: | 4 |
| Credit value: | 15 |

## Aim

This unit enables learners to gain credit for work-based practical investigations either as an individual or as part of a team. Learners will plan, undertake, monitor progress and communicate the outcomes of a work-based topic.

## Unit abstract

Scientific work-based experience is an important aspect of all practical subjects. For part-time learners their day-to-day activities are a valuable source of learning and should be recognised. Company-based investigations often involve a team working on a common project with each individual carrying out a specific role and contributing key information to the final outcome. It is essential therefore that investigators are able to work safely and accurately, keeping detailed records of their activities and clearly communicating their findings.

This unit allows flexibility in terms of subject content and timescale. The investigation must be carried out in the workplace and the assignment set in an industrial context. The unit is intended for part-time learners in their place of work. This unit develops the skills of negotiation, planning, record keeping, safe practical investigation, report writing and communication.

This unit differs from *Unit 5: Project for Applied Science* as it must be carried out in the workplace and gives credit for work-based activity. The work used for this unit must not be used for either *Unit 5: Project for Applied Science or Unit 28: Work-based Experience.*

## Learning outcomes

On successful completion of this unit a learner will:

1. Be able to plan a work-based topic
2. Be able to keep a detailed logbook
3. Be able to undertake an extended work-based practical investigation
4. Be able to communicate the investigation and its results.

# Unit content

1 **Be able to plan a work-based topic**

*Work-based topic*: type eg team, individual; subject area related to HN curriculum

*Specification*: practical and literature based; scope and purpose of investigation; intended outcomes; methods of approach; resource requirements

*Resources*: existing equipment and materials; access to other equipment

*Amend schedule*: following discussions with supervisors eg agreed amendments to specification, timescales

*Supervisors*: work-based supervisor; academic supervisor

2 **Be able to keep a detailed logbook**

*Document work*: dated entries; details of methods used; instrument types and settings; observations; safety measures taken; advice sought; cooperative and own results; tabulated results according to scientific protocols regarding headings, units and significant figures

*Amend the schedule*: significant or unexpected events; deviations from expected data and results; progress made relative to original plan; agreed amendments with supervisor

3 **Be able to undertake an extended work-based practical investigation**

*Investigation*: experimental work; operating methods and procedures; acquisition of equipment and materials; methods of data collection and recording; accuracy and precision; quality standards; minimise errors; use statistical techniques

*Safe practice*: safety manuals; safety equipment; COSHH analysis; risk assessments

*Autonomy*: amendments to schedule; practical work; contributions to group work; discussions with supervisors; proposals for additional work

*Agreed plans*: documented arrangements for group work; agreed deadlines

4 **Be able to communicate the investigation and its results**

*Conclusions*: analysis of data and experimental observations; justification in terms of original specification

*Scientific report*: abstract; introduction and objectives; literature review; results in their fully processed form; raw data, spectra etc included as an appendix; experimental work; discussion; areas of further investigation; appendices; bibliography

*Formats*: in-text referencing and bibliography according to accepted scientific methodology; third person past tense; tabulated results

*Specification*: practical and literature based; scope and purpose of investigation; intended outcomes; methods of approach; resource requirements

*Presentation*: appropriate media; style appropriate to audience; clear explanations of scope and results; justify conclusions

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
| --- | --- |
| LO1 Be able to plan a work-based topic | 1.1 propose a work-based topic that relates to the programme of study<br>1.2 produce an outline specification for the topic<br>1.3 list required resources and support procedures<br>1.4 amend the schedule as appropriate following consultations with supervisors |
| LO2 Be able to keep a detailed logbook | 2.1 document work undertaken in a systematic manner<br>2.2 amend the schedule as appropriate<br>2.3 distinguish between own results and group results |
| LO3 Be able to undertake an extended work-based practical investigation | 3.1 undertake the investigation, working accurately and following safe practice protocols<br>3.2 demonstrate substantial and appropriate degrees of autonomy<br>3.3 execute shared work according to agreed plans |
| LO4 Be able to communicate the investigation and its results | 4.1 justify conclusions drawn from the results of the investigation<br>4.2 produce a scientific report of the investigation using accepted formats suitable for use by an industrial line manager<br>4.3 explain the extent to which the specification has been met<br>4.4 deliver a presentation summarising the investigation |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 4: Chemical Laboratory Techniques*
- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 7: Laboratory Management*
- *Unit 22: Management of Projects*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

## Delivery

This unit differs from *Unit 5: Project for Applied Science* in that it must be carried out in the workplace and gives credit for work-based activity. The work used for this unit must not be used for either *Unit 5: Project for Applied Science or Unit 28: Work-based Experience.* This *Work-based Investigation* unit places greater emphasis on record keeping, negotiating skills and autonomy.

For learning outcome 1, learners must demonstrate that they can plan a work-based project in cooperation with their supervisors. All learners require a named and suitably qualified industrial supervisor as well as an academic supervisor. The planning stage is crucial and should be carried out jointly by the learner and both supervisors. Supervisors should agree protocols jointly for monitoring learner performance and independence of effort. The chosen topic may be part of a team investigation but sufficient documentation must be kept to clearly demonstrate the individual work of each learner.

For learning outcome 2, learners must keep a dated, day-to-day logbook listing details of all work undertaken and results obtained. Logbook entries should be completed either during or immediately after each session spent on the topic. The logbook must distinguish clearly between team member results and observations and those undertaken by the individual learner. It should also record details of meetings and discussions with supervisors.

For learning outcome 3 it is envisaged that the industrial supervisor will be mainly responsible for overseeing the project and ensuring that it is carried out safely. The industrial supervisor should have regular meetings with the learner during the experimental period to guide and, where appropriate, comment on the direction of the project. They will also be responsible for ensuring that the learner carries out substantial independent activity.

For learning outcome 4, learners must produce a scientific report and deliver a presentation (preferably PowerPoint) summarising the investigation and its results. The report should be produced in accordance with industrial reporting protocols. Clear guidelines for the style and content of the industrial report should be agreed and documented, but in all cases reports must be produced using a recognised scientific format. Suggestions for further work should relate to minimising errors, extending the topic area, confirming or supporting conclusions etc.

## Assessment

The work used for this unit may be part of the learner's normal workload or an activity designed specifically to deliver the required evidence, or a combination of the two. In either case, the negotiation and planning required for learning outcome 1 must be completed and agreed before detailed practical work begins. The process of the work and its recording for learning outcomes 2 and 3 should follow normal site practices as closely as possible.

The format of the final report for learning outcome 4 should be determined at the planning stage. Supervisors must set a deadline to see a draft version of the early sections (not the whole report), and provide feedback on these. Amendment and completion of the final report should then take place without further assistance or comment from either supervisor. The presentation should be made to supervisors and fellow learners and may or may not include peer assessment. Input from fellow employees is encouraged. If the presentation is to be used as evidence for higher grading criteria then minimum guidance should be given.

## Resources

The work for this unit will normally be achievable within the resource constraints of the employer. Additional use of resources at the centre may be appropriate in specific cases. For example laboratory facilities or resources to develop the report and/or presentation.

## Employer engagement and vocational contexts

Work for this unit should be carried out in the workplace under the direct supervision of the works supervisor, in consultation with the academic supervisor.

# Unit 9: Inorganic Chemistry of Crystal Structures and Transition Metal Complexes

| | |
|---|---|
| Unit code: | M/601/0360 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

This unit enables learners to gain an understanding of the first row d block elements. The three main areas covered are the solid state, the first row d block metals and their complexes and catalysis.

## Unit abstract

This unit is an in-depth study of some current aspects of inorganic chemistry. The solid state, the first row d block elements and transition metal complexes are examined in detail. These topics are then expanded to cover homogeneous and heterogeneous catalysis.

The unit offers opportunities for learners to research specialised areas and is appropriate for employees working in a research environment or for learners wishing to work in this area or to continue study at a higher level.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the structure of crystalline materials

2 Understand first row d block metal chemistry

3 Understand models of bonding in transition metal coordination complexes

4 Be able to report on homogeneous and heterogeneous catalysis.

# Unit content

1 **Understand the structure of crystalline materials**

*Metallic crystal structures*: bcc - body centred cubic; ccp - cubic close-packed (face-centred cubic) and hcp - hexagonal close packed structures; examples of metals adopting bcc, ccp and hcp; coordination number of bcc, ccp and hcp structures; unit cells; packing efficiency

*Ionic crystal structures*: use of x-ray crystallography for determining structure; MX and $MX_2$ structures including coordination number; ionic radii; limiting radius ratios for NaCl and CsCl structures; structural predictions from radius ratio rule; Born-Haber cycles and lattice enthalpies; factors affecting lattice enthalpies for halides of groups 1 and 2

*Theoretical model for ionic crystal lattice*: forces of attraction and repulsion between point charges, use of Madelung constant; Born exponent; Born-Lande equation; calculation of lattice enthalpy; comparison of Born-Lande theoretical value of lattice energy with experimental values from Born-Haber cycle

2 **Understand first row d block metal chemistry**

*Electron arrangements*: distinction between the terms transition metal and d block metal as given by IUPAC definitions; the electronic arrangement of the first row d block metals Sc-Zn, including the deviation of Cr and Cu; order of filling (4s before 3d) and order of loss on cation formation (4s lost before 3d)

*Chemistry of first row d-block elements*: trends in oxidation states; oxides and halides; redox reactions of first row d block metals; use of standard reduction potentials; $[Cr_2O_7]^{2-}$ and $[MnO_4]^{-}$ as examples of powerful oxidising agents; hydrolysis eg $[Sc(H_2O)_6]^{3+}$ gives acidic solutions in water

*Coordination chemistry*: ligands; denticity to include examples of monodentate, bidentate, tridentate and ethylene diamine tetra-acetic acid (EDTA) as a hexadentate ligand; formation of complexes; coordination numbers and coordination geometry limited to examples of tetrahedral, square planar, octahedral; naming coordination compounds; isomerism to include structural isomerism, ionisation, hydrate, coordination, linkage and stereoisomerism; geometric and chiral complexes

*Stability of complexes*: ligand exchange; coordination equilibria; stability constants; stepwise formation constants; trends in formation constants; chelate effect

*Experimental work*: suitable experiments illustrating relevant content eg colours of complexes, colorimeter or UV experiments, ligand exchange and stability constants

3 **Understand models of bonding in transition metal coordination complexes**

*Crystal field model*: shapes and orientations of d orbitals; crystal field splitting effects in octahedral and tetrahedral complexes; crystal field splitting parameter; spectrochemical series; effect of metal ion on crystal field splitting parameter; absorption spectra; stabilisation energy; high and low spin configurations; magnetic properties (diamagnetic and paramagnetic); Gouy balance

*Ligand field model*: comparison of crystal field and ligand field theory; combination of metal and ligand orbitals to give molecular orbitals; energy level diagrams for simple systems ($\sigma$ bonds only)

4 **Be able to report on homogeneous and heterogeneous catalysis**

*Catalysts*: homogeneous and heterogeneous; catalytic efficiency; catalytic cycles; energetic; selectivity; lifetime; poisoning

*Homogeneous catalysis*: industrial eg alkene hydrogenation, hydroformylation (Oxo-process), methanol carbonylation (ethanoic acid synthesis); recent advances to include polymer supported catalysts; biphasic catalysis

*Heterogeneous catalysis*: surface properties of heterogeneous; physisorption and chemisorption; desorption; catalytic converters; hydrogenation of alkenes; ammonia synthesis; oxidation of sulfur (IV) oxide; structure and applications of zeolites

## Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the structure of crystalline materials | 1.1 explain the structures of metals<br>1.2 explain the structure of ionic crystal structures<br>1.3 analyse data using specified methods for determining lattice enthalpy |
| LO2 Understand first row d block metal chemistry | 2.1 discuss electron arrangements and explain the chemistry of first row d block metals<br>2.2 explain specified coordination chemistry of first row d block metals<br>2.3 discuss the stability of complexes in terms of stability constants<br>2.4 explain experimental observations in terms of the relevant theory |
| LO3 Understand models of bonding in transition metal coordination complexes | 3.1 discuss the application of crystal field theory to account for behaviour of tetrahedral and octahedral complexes of first row d metal elements<br>3.2 discuss the application of ligand field theory to account for behaviour of octahedral complexes of first row d metal elements<br>3.3 compare the ligand field and crystal field approach to bonding in complexes |
| LO4 Be able to report on homogeneous and heterogeneous catalysis. | 4.1 report on how catalysts function<br>4.2 review industrial homogeneous catalysis<br>4.3 research the use of industrial heterogeneous catalysts including characteristics of their mode of action |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 12: Analytical Chemistry*
- *Unit 14: Industrial Chemistry*.

## Essential requirements

## Delivery

There are a number of opportunities to integrate the use of computer software or interactive internet sites. This is particularly valuable when dealing with complex three dimensional structures. Specific examples include hcp, ccp and bcc packing arrangements, visual examples of complex ionic structures, transition metal complexes and d orbital diagrams. There are now many online video demonstrations of coordination chemistry and these may be useful when resources are limited.

## Assessment

Learning outcome 1 may be assessed via a structured assignment, although centres may wish to involve some practical tasks, for example using molecular model kits for packing structures. It is advisable to assess learning outcomes 2 and 3 together since they are closely related topics. However, there is flexibility in the assessment of the other learning outcomes. Learning outcome 4 could be assessed in isolation as a learner-centred literature research project.

## Resources

Equipment for practical work should be within normal laboratory resources.

The Royal Society of Chemistry website (www.rsc.org) has a large range of resources including the CD ROM *The Molecular World* series: Molecular Modelling and Bonding.

## Employer engagement and vocational contexts

The unit content, especially learning outcome 4, may have local relevance. Use of site visits or guest speakers would enhance delivery.

# Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds

| | |
|---|---|
| Unit code: | A/601/0362 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

This unit covers understanding of aromaticity and optical activity. The chemistry of aromatic and carbonyl compounds are examined with respect to reaction mechanisms and use in synthesis.

## Unit abstract

This unit develops and enhances the knowledge of organic chemistry that underpins both the industrial chemistry and the biological applications of organic molecules. The unit covers the concept of aromaticity and examines the chemistry of aromatic and carbonyl compounds from the viewpoint of their reactions, mechanisms and use in synthesis. Stereochemistry and functional group chemistry are also studied to unify the underlying chemistry.

The concept of aromaticity together with mechanisms for electrophilic substitution in both aromatic and substituted aromatic compounds are examined. Knowledge of these mechanisms is used to rationalise an understanding of the use of aromatic compounds in the synthesis of di- and tri-substituted benzene derivatives. The organic chemistry of carbonyl compounds is treated in a similar manner with knowledge of mechanistic pathways being used to support their varied synthetic uses.

The unit concludes by focusing on aspects of optical isomerism including stereochemical representation and nomenclature. The relevance of stereochemistry in chemical reactions and biological systems is considered in terms of asymmetric synthesis and examples of biologically active compounds.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the structure of aromatic compounds

2 Understand the synthetic use of substitution reactions of aromatic compounds

3 Understand the synthetic use of carbonyl compounds

4 Understand structures and reactions of optically active molecules.

# Unit content

1 **Understand the structure of aromatic compounds**

*The electronic structure of benzene*: physical structure; methods of representation; bonding, $sp^2$ hybridisation, bond lengths, resonance, stabilisation in terms of resonance energy or delocalisation energy; molecular orbital model

*Experimental evidence*: hydrogenation enthalpy; bond lengths; resistance to typical electrophilic addition reactions

*Categorise aromatic hydrocarbon systems*: identification of aromatic and anti-aromatic hydrocarbon systems using Hückel's rule to the following systems (planar, fully conjugated, monocyclic systems with $4n + 2$ $\pi$ electrons)

*Aromatic heterocycles*: application of Hückel's rule to simple heterocyclic systems eg pyridine, pyrrole, furan

*Experimental data*: use of chemical and spectroscopic evidence to elucidate structures eg characteristic $^1H$ NMR signals of aromatic hydrogens, characteristic infrared bands

2 **Understand the synthetic use of substitution reactions of aromatic compounds**

*Mechanisms of electrophilic substitution*: nitration; sulfonation; Friedel-Crafts alkylation; Friedel-Crafts acylation and halogenations using halogen carrier

*Reactivity of substituted benzenes*: in electrophilic substitutions; effect of existing substituent on rate and position of further electrophilic substitution; nucleophilic substitution; effect of leaving groups; use in synthesis

*Synthetic pathways*: applications to synthesis of di-substituted and tri-substituted benzene compounds

*Commercial applications*: examples of substituted benzenes eg ibuprofen, salbutamol, aspirin, paracetamol, phenols

3 **Understand the synthetic use of carbonyl compounds**

*Acidity of carbonyl compounds*: acidity of $\alpha$-hydrogens and formation of enolate ions; enolisation of carbonyl compounds including aldehydes, ketones and esters; use of equilibrium constants as a measure of stability of carbonyl compound relative to corresponding enol; examples of stable enols eg those that form intramolecular hydrogen bonds; acid catalysed $\alpha$ halogenations of aldehydes and ketones; halogenations of aldehydes and ketones in base eg haloform reaction, iodoform test

*Aldol addition and aldol condensation*: base catalysed aldol addition reactions; dehydration of aldol addition products leading to formation of $\alpha,\beta$-unsaturated carbonyl compounds; crossed aldol reactions eg Claisen-Schmidt condensation

*Condensation reactions involving ester enolate ions*: Claisen condensation and crossed Claisen condensations; synthesis using Claisen condensations eg $\beta$-□keto esters, $\beta$-diketones

*Alkylation of ester enolate ions*: malonic ester synthesis; acetoacetic ester synthesis

*Conjugate addition reactions:* conjugate addition to α,β unsaturated carbonyl compounds eg α,β-unsaturated esters, α,β-unsaturated ketones, enolate ions, Michael addition, Robinson annulations; conjugate addition reactions versus carbonyl addition as an example of kinetic versus thermodynamic control

4 **Understand structures and reactions of optically active molecules**

*Chiral molecules*: molecules containing chiral carbon atoms; R/S notation and nomenclature

*Optical rotation*: simple calculations involving optical rotation and specific optical rotation; racemic mixtures

*Resolution of enantiomers*: chemical and chromatographic resolution and separation of enantiomers

*Diastereoisomers*: limited to examples with two chiral centres; physical properties

*Stereochemical representations*: use of molecular models to demonstrate the stereochemical nature of molecules; Fischer and Newman projections; use of (R) and (S) sequence rules

*Reactions involving optical activity*: examples of reactions that involve optical isomers; formation of racemic mixtures; asymmetric synthesis

*Biological systems*: examples of optical isomerism in biological systems eg drug synthesis in the pharmaceutical industry, taste (flavours), sugars, amino acids, pesticides/fertilisers, natural products

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the structure of aromatic compounds | 1.1 explain the structure of benzene in terms of a delocalised $\pi$ system and molecular orbitals<br>1.2 review experimental evidence to support current model of benzene structure<br>1.3 categorise hydrocarbon and heterocyclic structures as aromatic or anti-aromatic using Hückel's rules<br>1.4 analyse experimental data to elucidate structures of aromatic compounds |
| LO2 Understand the synthetic use of substitution reactions of aromatic compounds | 2.1 explain, using mechanisms, specified electrophilic substitution reactions<br>2.2 explain the effect of substituent on electrophilic and nucleophilic reactivity of substituted benzenes<br>2.3 discuss different synthetic pathways for the synthesis of substituted benzene compounds<br>2.4 explain the importance of aromatic compounds in a commercial context |
| LO3 Understand the synthetic use of carbonyl compounds | 3.1 review acidity of carbonyl compounds in enolisation and explain the role of aldol reactions in synthesis<br>3.2 discuss the synthetic role of ester enolate condensation reactions<br>3.3 explain alkylation of ester enolates in a synthetic context<br>3.4 discuss synthetic pathways using conjugate addition reactions |
| LO4 Understand structures and reactions of optically active molecules | 4.1 explain (+) (-) and R/S notation and calculate optical rotations using given data<br>4.2 explain the resolution of enantiomers<br>4.3 discuss the properties of diastereoisomers<br>4.4 use Fischer stereochemical representations for R/S enantiomers<br>4.5 discuss reactions involving optical activity and the importance of optical activity in biological systems |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 2: Organic Chemistry*
- *Unit 4: Chemical Laboratory Techniques*
- *Unit 12: Analytical Chemistry*
- *Unit 14: Industrial Chemistry*
- *Unit 15: Biochemistry of Macromolecules and Metabolic Pathways*
- *Unit 16: Polymer Chemistry*
- *Unit 17: Medicinal Chemistry*.

## Essential requirements

## Delivery

Where possible, tutors must select illustrative material to emphasise the relevance of the learning outcomes to everyday life or industrial application.

It may be appropriate to develop and organise the unit in a relatively classical manner around a theme that illustrates concepts of organic chemistry. Possible themes and features include emphasis on industrial, biological, medical, environmental, cosmetics and nutritional applications of organic chemistry.

## Assessment

The learning outcomes can be treated individually if desired, although there are opportunities to integrate learning outcome 4 with some of the reactions in learning outcome 3. Similarly, learning outcomes 1 and 2 may be assessed together since they are both aromatic themes.

## Resources

Learners will need access to library and information technology resources, tutorial and technical support, molecular models and laboratory facilities to demonstrate experiments.

## Employer engagement and vocational contexts

Where possible, the content should be delivered within a vocational context. The emphasis should be on synthetic routes and there are numerous industrial examples. Site visits or visiting speakers may also enhance content.

# Unit 11: Physical Chemistry of Spectroscopy, Surfaces and Chemical and Phase Equilibria

Unit code: J/601/0364

Level: 5

Credit value: 15

## Aim

This unit develops an understanding of physical chemistry topics that have relevance to industrial chemistry through study of phase and chemical equilibria, spectroscopy and surface chemistry.

## Unit abstract

This unit covers the kinetic theory of gases, chemical equilibrium, phase equilibria, spectroscopy, surface chemistry and colloids through a programme of related practical and assignment work.

This unit involves interpretation of phase diagrams, calculations involving chemical and phase equilibria and understanding models used to explain spectroscopy and the properties of surfaces.

Understanding equilibria is important in chemical engineering applications. Spectroscopic models are useful in explaining how matter interacts with electromagnetic radiation and the information that may be gained from spectroscopic measurement. Understanding surface chemistry is important in catalysis, the detergent industry and polymer industry.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to apply the concept of chemical equilibrium

2 Understand physical equilibria in one and two component systems

3 Understand the origins and applications of molecular spectroscopy

4 Understand properties of surface chemistry.

# Unit content

1 **Be able to apply the concept of chemical equilibrium**

*Kinetic theory of gases*: inherent assumptions; collision theory; Maxwell distribution of speeds; Boyle's Law; Charles's Law; Avogadro's Hypothesis; relationship between pressure and temperature, ideal gas constant, $pV = nRT$; real gases; deviations from ideal behaviour; other equations eg Van der Waals, virial

*Calculations*: calculations of one term in the ideal gas equation, given the other four, calculation of one variable when another is changed and the rest are held constant (eg $p_1V_1 = p_2V_2$)

*Equilibrium constants*: mole fraction; partial pressure; relationship between partial pressure, total pressure and mole fraction; $K_x$; $K_c$; $K_p$; interconversion of $K_x$, $K_c$, $K_p$; suitable examples

*Problems involving chemical equilibrium*: numbers of moles of substances in chemical equilibrium with each other; calculation of $K_x$, $K_c$, $K_p$; $\Delta G = \Delta G^{\theta} + RT\ln K$; $\Delta G = 0$ as a condition for chemical equilibrium; use of $\Delta G^{\theta} = -RT\ln K$; calculation of $K_p$ from values of $\Delta H^{\theta}$ and $\Delta S^{\theta}$; van't Hoff Isochore; $\ln K = -\Delta H^{\theta}/RT + \Delta S^{\theta}/R$; shape of plots of lnK versus 1/T; $\ln(K_2/K_1) = -(\Delta H^{\theta}/R)(1/T_2 - 1/T_1)$; calculation of $K_p$ at different temperatures; interpretation of the magnitude of equilibrium constant

2 **Understand physical equilibria in one and two component systems**

*Simple one-component systems*: carbon dioxide; water; sulfur; phase boundaries; triple points; use of phase rule for prediction of the number of degrees of freedom at given points on phase diagrams; interpretation of phase diagrams

*Clapeyron and Clausius-Clapeyron equations*: calculations; appreciation of the importance of the sign of the change in volume and the enthalpy associated with phase changes in Clapeyron equation; applicability of Clausius-Clapeyron equation; inherent assumptions in Clausius-Clapeyron equations

*Liquid-vapour equilibria*: mole fraction and percentage composition; composition of liquid phase; composition of vapour phase in equilibrium with liquid phase for an ideal mixture; vapour pressure/composition diagrams and boiling point/composition diagrams for ideal binary mixtures and for binary mixtures, exhibiting positive or negative deviation from Raoult's Law; simple and fractional distillation; azeotropes; carrying out distillation of binary mixtures eg petroleum ether, water/methanol, water/propanone

*Solid-liquid equilibria*: ideal mixtures; interpretation of phase diagrams; eutectic diagram; melting point; composition of liquid and solid phases in equilibrium; carrying out practical work related to construction of a phase diagram; risk assessment of substances involved eg acetanilide and benzoic acid

3 **Understand the origins and applications of molecular spectroscopy**

*Spectroscopic techniques*: microwave; infrared; visible spectroscopy; wavelength wavenumber, electromagnetic spectrum, Beer-Lambert Law

*Theoretical models*: energy within molecules: quantised energy levels; types of energy within molecules; transitions between energy levels; rotational levels; vibrational levels; electronic levels; absorption and emission of radiation; population of energy levels

*Rotational spectroscopy*: rigid rotor model for diatomic molecules; moment of inertia; rotational quantum number J; statistical weight; rotational constant B; energy of levels; selection rule; differences between levels; spacing of lines; vibrational spectroscopy; simple harmonic oscillator model; vibrational energy changes; normal modes of vibration; energy of levels; selection rule; fundamental vibrational frequency; relationship of infrared spectra to structures; anharmonic oscillator model; comparison between harmonic oscillator model and anharmonic oscillator model; electronic transitions: electronic energy changes; relationship of absorption to atomic/molecular structures, chromophores; energy associated with $\sigma \rightarrow \sigma^*$, $\pi \rightarrow \pi^*$ , $n \rightarrow \sigma^*$, $n \rightarrow \pi^*$ transitions; effect of solvent on ultraviolet frequencies (blue shift and red shift); effect of conjugated double bonds on wavelength; energy associated with d-d transition in transition metal complexes; Beer-Lambert Law; molar extinction coefficient

*Applications*: use of vibrational and electronic spectra in qualitative analysis; use of spectra in quantitative analysis; comparison of infrared spectra with different functional groups; comparison of ultraviolet spectra with different chromophores; visible spectra of aqueous solutions of $Cu^{2+}$, $Co^{2+}$, $Ni^{2+}$, $MnO_4^-$; estimation of molar extinction coefficient for visible and ultraviolet spectra

4 **Understand properties of surface chemistry**

*Solid-gas interface*: physical adsorption; chemisorption; meaning of the term ‘isotherm’; derivation of the Langmuir isotherm and inherent assumptions; assumptions inherent in the BET isotherm; simple surface catalysis of gas phase reactions eg hydrogenation of ethene

*Nature and properties of surface-active agents*: surface and interfacial tensions; surface activity; surfactants (anionic, cationic, non-ionic); counterions; micelles; reverse micelles; detergency; specific uses of surfactants; change of contact angles and wetting

*Charged interfaces*: contact angles and wetting; description of the electric double layer; descriptive account of Helmholtz, Gouy-Chapman and Stern models of the double layer with respect to ionic distribution and electrical potential

*Colloidal systems*: classification; association colloids; polymer solutions; colloidal dispersions; classification of colloidal dispersions; properties of colloidal systems eg light scattering, turbidity; stability of colloidal dispersions; observation of properties for specific systems

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to apply the concept of chemical equilibrium | 1.1 account for the relationships between the variables in the ideal gas equation in terms of the kinetic theory of gases<br>1.2 calculate terms in the ideal gas equation<br>1.3 write expressions for calculating chemical equilibrium constants<br>1.4 solve problems involving chemical equilibrium |
| LO2 Understand physical equilibria in one and two component systems | 2.1 analyse pressure/temperature phase diagrams for simple, one-component systems<br>2.2 perform calculations using the Clapeyron and Clausius-Clapeyron equations<br>2.3 explain liquid-vapour equilibria and distillation in terms of vapour pressure/composition and boiling point/composition plots for two component systems<br>2.4 analyse phase diagrams for solid-liquid equilibria which form a simple eutectic mixture |
| LO3 Understand the origins and applications of molecular spectroscopy | 3.1 examine the relationship between spectroscopic techniques and electromagnetic radiation<br>3.2 review theoretical models used in spectroscopy<br>3.3 explain the applications of practical spectroscopic techniques |
| LO4 Understand properties of surface chemistry | 4.1 explain the solid-gas interface<br>4.2 explain the nature and properties of surface active agents<br>4.3 discuss features of the solid-liquid interface<br>4.4 discuss the behaviour of colloidal systems |



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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 3: Physical Chemistry*
- *Unit 4: Chemical Laboratory Techniques*.

## Essential requirements

## Delivery

Learners must be encouraged to explain relationships in terms of the kinetic theory of gases. Learners must explore the limitations of the ideal gas equation and the reasons for the correction factors introduced in the Van der Waals equation.

The relationship between concentration and pressure should be derived from the ideal gas equation. Learners must be able to write expressions for $K_x$, $K_c$ and $K_p$ and relate $K_p$ to both $K_x$ and $K_c$.

The necessary condition for equilibrium $\Delta G = 0$ must be introduced. This then leads to $\Delta G^\theta = -RT\ln K$. This relationship may be used for gas phase reactions to calculate $K_p$ from values of $\Delta G^\theta$ which may be calculated from values of $\Delta H^\theta$ and $\Delta S^\theta$. Learners must be able to comment on the magnitude of the equilibrium constant and where there are significant amounts of reactants and/or products in the equilibrium mixture. The van't Hoff Isochore must be introduced. Learners should be able to use graphs relating to $\ln K = -\Delta H^\theta/RT + \text{constant}$ and perform calculations using $\ln(K_2/K_1) = -(\Delta H^\theta/R)(1/T_2 - 1/T_1)$. Learners must be able to comment on the values of equilibrium constant at different temperatures.

Understanding phase equilibria is fundamental to the chemical process industry. Where possible, learners must have the opportunity to carry out practical work linked to construction of phase diagrams. Learners should explore the implications of one-component phase diagrams, the meaning of the phase boundaries and triple points. This should be related to phase rule. The structure of the Clapeyron equation should be related to the structure of one-component phase diagrams.

The relationship between velocity, wavelength, frequency, wavenumber, energy and Planck's constant must be established and the energy differences corresponding to microwave, infrared, visible and ultraviolet electromagnetic radiation calculated. Learners should become familiar with the rigid rotor model for rotation of diatomic molecules, the simple harmonic oscillator and anharmonic oscillator models for infrared and the concept of chromophores for ultraviolet/visible spectroscopy.

Tutors must introduce the importance of physical adsorption and chemisorption to catalysis. Learners must be able to describe surface catalysis. Learners should get the opportunity to observe phenomena relating to surface activity, like surface tension. The formation of micelles and its commercial significance must be explained. The nature of reverse micelles and their application in the oil industry must be explained. Tutors must introduce the three models for describing electrical double-layers on a charged surface. This should be pictorial and descriptive.

## Assessment

Learners must perform straightforward calculations involving the ideal gas equation. They should incorporate simple unit conversions – for example $cm^3$ to $m^3$, $^0C$ to K, bar to Pa etc.

Learners must show how expressions for $K_x$ and $K_p$ and $K_c$ are interrelated using algebra. They must calculate $\Delta G^\theta$ from values of $\Delta H^\theta$ and $\Delta S^\theta$ and calculate $K_p$ from $\Delta G^\theta = -RTlnK$. They need to plot values of lnK against values of 1/T to obtain $\Delta H^\theta$, to explain the sign of the slope of the plot in relation to the sign of $\Delta H^\theta$ and to calculate as a minimum $\Delta H^\theta$ values from the equation $\ln(K_2/K_1) = -(\Delta H^\theta/R)(1/T_2 - 1/T_1)$.

Learners must complete at least one straightforward calculation using the Clapeyron equation and one with the Clausius-Clapeyron equation.

Learners must provide evidence that they can use the concept of mole fractions or percentage composition. They should demonstrate that they can work out the composition of vapour in equilibrium with a liquid of given composition for an ideal mixture. Learners must relate the vapour pressure, composition plot to a plot of boiling point/mole fraction and explain the principles of simple and fractional distillation of ideal mixtures. Learners must explain the shape of vapour pressure/composition plots and boiling point/composition plots for mixtures exhibiting positive and negative deviation from Raoult's Law. They must also show that they understand the origin of maximum and minimum boiling azeotropes. Where possible, distillation processes should be related to local industrial processes.

Solid/liquid phase diagrams are relevant to chemical process in relation to crystallisation. Learners must provide evidence of carrying out some practical work on this topic to show understanding of how a phase diagram is constructed. Learners must also interpret a given phase diagram for a two component system where a simple eutectic is formed.

In assessing the relationship between spectroscopic techniques and the molecular interactions of the energy of the electromagnetic radiation for learning outcome 3, learners must show that they know the wavelength, frequency and velocity of each type of radiation and understand the nature of the transition caused by the absorption of radiation. Learners must demonstrate their understanding of the aspects of content relating to the rigid rotor model for microwave spectroscopy, simple harmonic oscillator model and anharmonic oscillator models for infrared spectroscopy. They also need to show understanding of d to d transitions in transition metal complexes and of the concept of chromophores and related $\sigma \rightarrow \sigma^*$, $\pi \rightarrow \pi^*$, $n \rightarrow \sigma^*$, $n \rightarrow \pi^*$ transitions for ultraviolet spectroscopy of organic molecules in-line with the unit content. Learners must explain how microwave spectroscopy may be used to estimate bond lengths and how qualitative and quantitative infrared and ultraviolet spectroscopy may be used. They also need to demonstrate an understanding of how a Beer-Lambert method may be developed. There should be an awareness of the magnitude of the molar extinction coefficient in relation to the types of compound involved and how that would affect the Beer-Lambert method developed.

The limitations and successes of the Langmuir isotherm and the reasons behind the development of the BET isotherm must be explained. The properties of surfactants in lowering surface tension and in cleaning must be explained, including consideration of formation of micelles and reverse micelles. The Helmholtz, Gouy-Chapman and Stern double layer models must be discussed. Learners must give examples of types of colloidal systems such as polymer solutions, association colloids and colloidal dispersions. They must discuss the properties of colloidal systems, for example light scattering and turbidity. Learners must also discuss factors which affect the properties of colloidal dispersions.

## Resources

Learners will need access to appropriate laboratory facilities, technical support and to library and information technology resources.

## Employer engagement and vocational contexts

Delivery of this unit will be greatly enhanced by industrial visits and talks from speakers from industry. Understanding phase equilibria is very important in relation to distillation and crystallisation.

# Unit 12: Analytical Chemistry

| | |
|---|---|
| Unit code: | M/601/0410 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

The unit enables learners to understand and perform some key processes involved in analytical chemistry and to gain practical skills in undertaking extended practical investigations.

## Unit abstract

Chemical analysis plays a key role in the operation of industrial, biomedical and forensic science. This unit will provide the scientific principles, concepts and skills required to understand and perform some key processes involved in analytical chemistry. The unit covers a wide range of classical and modern analytical techniques, using a practical approach, whilst at the same time building in relevant theoretical concepts. The overall aim of this unit is to provide learners with opportunities to carry out extended investigations in a small group. The investigations should involve extended practical exercises or adopt a more open-ended project approach.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand how the analytical process is used systematically to prepare for analyses

2 Be able to undertake analytical separations

3 Be able to undertake quantitative analyses

4 Be able to apply spectroscopic techniques of analysis.

# Unit content

1 **Understand how the analytical process is used systematically to prepare for analyses**

*Define the problem*: type of analytical process eg separation, quantitative analysis, spectroscopic analysis

Prepare for analysis: literature survey

*Analytical method*: choice of method; sampling; preliminary sample treatment; separation of analyte; final method of analysis; method validation

*Evaluate results*: data collection, data manipulation; critical analysis of results; presentation of results in an appropriate format

2 **Be able to undertake analytical separations**

*Method selection*: selected technique based on nature of mixture components; type of contaminants; quantities to be separated; volatility/solubility of components

*Selected techniques*: solvent extraction; principles; selectivity based on pH control and complexation; methods of extraction; chromatography: principles and application of partition and adsorption as applied to separation of samples using paper, thin layer, column, gas and high performance chromatography; GLC and HPLC (injection, columns, stationary and mobile phases, temperature control, detectors, retention time, quantitative analysis using internal standards, standard addition); ion exchange (types of ion exchange resin, kinetics of exchange, selectivity of resins, use in separation and concentration of analyte); electrophoresis (principles of zone electrophoresis as applied to separation of samples using media of paper and/or gel, effect of pH, temperature, ion strength, electro-osmosis)

*Conditions*: choice of stationary phase; choice of mobile phase; detection methods; temperature settings; selection of internal standards

*Calibration*: calibrate equipment relative to known standards

*Undertake separations*: separate mixtures; evaluate results; report findings

3 **Be able to undertake quantitative analyses**

*Titrimetry*: acid-base; redox; complexometric; precipitation; potentiometric

*Gravimetry*: reaction between analyte and reagent in solution to give sparingly soluble salts; filtration; drying; ignition; weighing of precipitates

*Appropriateness of techniques*: justify selection of method

*Calibration*: calibrate equipment relative to known standards

*Accuracy and precision*: differentiate between accuracy and precision; determine parameters from measurements

*Process data*: data collection and manipulation; error analysis; evaluation of results

4 **Be able to apply spectroscopic techniques of analysis**

*Spectroscopic techniques*: atomic spectroscopy (flame emission, instrumentation, interferences and applications); atomic absorption (instrumentation, interferences and applications); molecular spectrometry (visible and ultraviolet, infrared, nuclear magnetic resonance, mass spectrometry, principles, instrumentation, applications of each technique); Beer-Lambert Law; visible and ultraviolet (electronic transitions in molecules, chromophores, modification of chromophoric absorption by surrounding molecular structure, solvent effect, use in determining concentration); infrared (fundamental bands, characteristic group wave numbers, overtones, combination bands); nuclear magnetic resonance (spin transitions and resonance, chemical shift, spin/spin coupling, first order splitting pattern); mass spectrometry (molecular ion, base peak, molecular fragmentation processes, use of high resolution measurements)

*Use of combined techniques in structure elucidation*: appropriate combination of spectroscopic techniques to confirm structure of simple unknowns or molecular fragments

*Calculation of results of analyses*: reacting masses and volume; concentration and dilution of a solution; percentage composition

*Statistical methods*: true result; accuracy; precision; spread; deviation; standard deviation; variance

*Errors*: determinate and indeterminate; reliability of measurements; evaluation of data

*Confidence limits*: in terms of the final result

*Reporting results*: tables; charts; graphs and narrative created by hand and computer packages; verbal reports

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand how the analytical process is used systematically to prepare for analyses | 1.1 define the problem<br>1.2 undertake a literary search to prepare for analysis<br>1.3 explain the methods of sampling, separation and validation of the analytical method<br>1.4 evaluate results and present in an appropriate format |
| LO2 Be able to undertake analytical separations | 2.1 select a method to separate or concentrate the sample<br>2.2 explain the appropriateness of the selected technique to the selected analysis<br>2.3 identify the conditions appropriate to the analysis<br>2.4 calibrate equipment as appropriate and safely undertake analytical separations |
| LO3 Be able to undertake quantitative analyses | 3.1 use titrimetric and gavimetric methods to analyse a sample, using safe practices<br>3.2 explain the appropriateness of the selected techniques to the selected analyses<br>3.3 calibrate equipment as appropriate and record measurements to specified accuracy and precision<br>3.4 process experimental data |
| LO4 Be able to apply spectroscopic techniques of analysis | 4.1 use spectroscopic techniques to analyse samples and interpret results<br>4.2 select combined techniques to elucidate proposed structures<br>4.3 calculate results using appropriate mathematical/statistical methods to process results<br>4.4 identify errors in the methods used and determine the confidence limits of the final result<br>4.5 report the results of analyses appropriately |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

*Unit 4: Chemical Laboratory Techniques*

*Unit 6: Analysis of Scientific Data and Information*

*Unit 7: Laboratory Management*

*Unit 22: Management of Projects*

*Unit 27: Statistics for Experimental Design*.

## Essential requirements

## Delivery

The classical techniques of solvent extraction, gravimetry and titrimetry must be included. Automatic titrimetry, detection of end points by potentiometric and conductometric means and the use of redox, precipitation and complexometric techniques could be used.

It is anticipated that learners will work in small groups acting as a project team. They will make decisions about the work to be carried out, the literature searches required, the timescale, and the processing and presentation of the results. Practical tasks must include risk analyses consistent with COSHH guidelines.

## Assessment

Assignments must be designed to allow investigation rather than being a prescriptive list of the steps required. Learners will then decide how to approach and complete the analytical problem.

The outcome of these assignments will be a number of reports or presentations, which will provide evidence that learners have met the criteria. The reports may be written or verbal, or presented in other appropriate formats. If group reports are produced, it must be clear that each team member has met the criteria on an individual basis for their contribution to the overall process.

## Resources

This unit requires access to a range of classical and spectroscopic, chromatographic and electrophoretic instrumentation.

Ideally, learners should have the opportunity to use all the identified analytical techniques. However all learners must use infrared, ultraviolet/visible, nuclear magnetic resonance and gas and liquid chromatography and any three of the following: flame emission, atomic absorption and mass spectrometers, ion exchange and paper/gel electrophoresis. The theoretical principles of all techniques must be studied by all learners.

Learners will need access to a wide range of analytical equipment. It is important that learners develop an understanding of the analytical process, rather than mastering every technique. Where centres do not possess all of the necessary equipment, they could make arrangements to use instruments in industry or form links with neighbouring educational establishments.

## Employer engagement and vocational contexts

Learners would benefit from visits to industrial laboratories to observe practical analytical investigations in operation.

# Unit 13: Environmental Chemical Analysis

Unit code: T/601/0411

Level: 5

Credit value: 15

## Aim

The unit applies chemical principles to understanding environmental contexts. The complexity of sampling within the environmental matrix and appropriate strategies for accurate analyses are examined.

## Unit abstract

All industrial chemical processes are analysed for their environmental impact and many industries routinely carry out environmental monitoring and pollution control on a 24 hour basis.

This unit uses knowledge gained from the core units covering organic, inorganic, physical and analytical chemistry and applies it to the complex requirements of environmental analysis. Learners will learn how the chemical and physical properties of materials influence their transport in the natural environment.

Key analytical chemistry techniques of sampling, storage and analysis are reinforced through laboratory exercises. Learners are introduced to the specific requirements of environmental analysis, for example chemical analysis in the field, continuous sampling procedures and the use of remote sensing. Industrial visits allow learners to observe typical sampling protocols and the training required by the operatives involved. Those learners who work on an industrial site where effluent treatment takes place should be encouraged to research the treatment process. Those not in a suitable industrial setting should have opportunity for site visits to better understand the complexities of treatment processes.

There is opportunity to experience sampling in the field, coupled with planning for suitable controls, before chemical analysis takes place. This process provides an understanding of the difficulties of analysing complex, interactive and non-steady state chemical systems.

The use of climate change modelling in shaping economic activity is an important current issue. Through this unit, learners are encouraged to research the evidence and link the chemistry underpinning the modelling to the economic consequences of the model’s application.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand chemical principles in an environmental context

2 Understand how chemical analysis is used in environmental monitoring

3 Be able to carry out quantitative environmental analysis

4 Understand the applications of environmental modelling.

# Unit content

## 1 Understand chemical principles in an environmental context

*Distribution of neutral organic compounds*: sources; bioconcentration; accumulation in sediments; biomagnification; degradation

*Distribution of metal ions*: sources; solubilisation; deposition in sediments; uptake by organisms

*Mobilisation of chemical species*: influence of pH and redox conditions on mobilisation of inorganic and organic species

## 2 Understand how chemical analysis is used in environmental monitoring

*General approach to sampling*: sampling strategies eg spot and continuous sampling; sample extraction; storage; separation of interfering species

*Analytical techniques*: chromatographic, spectroscopic and electrochemical techniques

*Portable analytical equipment*: analysis of air, water and soil quality in the field; equipment design for field use; applications and limitations of portable analytical systems

*Remote sensing*: application eg current developments in remote sensing technologies

## 3 Be able to carry out quantitative environmental analysis

*The environmental matrix*: the complexity of the matrix and the difficulty of detecting analytes in the natural environment; factors affecting detection sensitivity

*Analytical schemes*: sampling methods; sample pre treatment; sample preparation eg extraction, dissolution, separation of interfering species, concentration of extracted analyte; analytical techniques

*Reference standards*: the importance of reference standards or effective matrix matching; advantages of standards additions (spiking) as opposed to calibration standardisation

*Water quality*: dissolved oxygen and oxygen demand in natural waters; comparison of biochemical and chemical oxygen demand and their relationship to specific concentrations of dissolved organic compounds; measurement of total organic carbon in water

## 4 Understand the applications of environmental modelling

*Chemical speciation modelling*: modelling the relationship between the chemical form of an element, mobility and bioavailability

*Environmental models and environmental qua*lity: the development of environmental models; acidification of upland environments through anthropogenic sulfur dioxide emissions; stratospheric ozone depletion modelling; climate change models linked to anthropogenic activity

*Impact of environmental models on economic activity*: changes in economic activity through predictive modelling eg alternative fuels for power generation, biofuels, energy conservation, carbon reduction targets

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand chemical principles in an environmental context | 1.1 explain methods by which organic materials are distributed in the environment<br>1.2 explain methods by which inorganic materials are distributed in the environment<br>1.3 explain the chemical principles which account for the mobilisation of chemical species in the environment |
| LO2 Understand how chemical analysis is used in environmental monitoring | 2.1 assess the importance of correct methods of sampling<br>2.2 review analytical techniques for determining the composition of environmental samples<br>2.3 explain how portable analytical instrumentation can be used for environmental sampling<br>2.4 discuss the application of remote sensing in environmental analysis |
| LO3 Be able to carry out quantitative environmental analysis | 3.1 demonstrate the complexity of the environmental matrix<br>3.2 implement analytical schemes appropriate for the natural environment<br>3.3 apply appropriate environmental reference standards in analysis of samples<br>3.4 measure the quality of a sample of water |
| LO4 Understand the applications of environmental modelling | 4.1 assess chemical speciation modelling as a viable alternative to an experimental study of environmental systems<br>4.2 explain the role of environmental models in predicting change given the concern over the current and future quality of the environment<br>4.3 assess the impact of the application of results of environmental models on economic activity |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

*Unit 1: Inorganic Chemistry*

*Unit 2: Organic Chemistry*

*Unit 3: Physical Chemistry*

*Unit 4: Chemical Laboratory Techniques*

*Unit 6: Analysis of Scientific Data and Information*

*Unit 12: Analytical Chemistry*

*Unit 19: Environmental Monitoring and Analysis*

*Unit 20: Environmental Management and Conservation*.

## Essential requirements

## Delivery

The complexity of sampling and analysis of the natural environment must be stressed. An appreciation of this must be gained through carrying out an appropriate analysis for learning outcome 3. Learners must select a suitable analysis with guidance from tutors. Sampling of the natural environment and planning for the use of reference standards may be undertaken as group work. The measurement of water quality may include simulated effluent for the determination of pH, chemical oxygen demand (COD), biological oxygen demand (BOD) and suspended solids.

Learning outcome 4 presents an opportunity to discuss current environmental models and their impact on economic activity. An example of this may be the impact of climate change modelling on government policies relating to carbon emissions. Guest speakers working on environmental modelling, or its impacts, would be a useful addition to the lecture programme.

## Assessment

Learning outcome 1 involves the principles of general chemistry as applied to the environment. Learning outcomes 2 and 3 involve the application of analytical techniques to environmental scenarios. These learning outcomes will involve laboratory investigations, fieldwork, and case studies to cover a wide range of analytical techniques. Learning outcome 4 will be mainly case study-based with consideration of suitable current environmental models.

## Resources

Learners require access to analytical instrumentation for practical exercises and computing facilities for research into environmental models.

## Employer engagement and vocational contexts

Learners would benefit from visits to industrial settings where effluent treatment and environmental monitoring can be observed. A visit to a sewage treatment works or water treatment facility would be helpful in setting environmental chemistry in the context of large-scale continuous processing.

# Unit 14: Industrial Chemistry

Unit code: F/601/0413

Level: 4

Credit value: 15

## Aim

The unit enables learners to gain an understanding of the factors affecting the successful operation and sustainability of an industrial process including its location, operation, health and safety and environmental issues.

## Unit abstract

The unit provides a flexible framework that will allow centres and learners to make a detailed study of an industrial process closely linked to their own interests, employer needs or local employment opportunities.

Learners will acquire an in-depth appreciation of all the factors that affect the successful operation of an industrial process and by applying chemical principles from other units achieve an understanding of the chemical processes involved in industrial manufacture.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand factors affecting the location of a chemical plant

2 Understand factors affecting the selection of a chemical process

3 Understand the physico-chemical aspects of an industrial process

4 Understand the chemistry of the industrial process.

# Unit content

1 **Understand factors affecting the location of a chemical plant**

*Location factors:* geological factors (drainage, waste removal); geographical factors (brownfield/greenfield, location, planning requirements); economic factors (subsidies, ESF support); environmental impact (location, sustainability, disposal of waste, treatment of effluent)

*Transportation costs*: raw materials; products; natural resources; energy; workforce

*Availability of resources*: energy; water; raw materials

*Environmental audit*: effect on nearby properties; waste disposal; deliveries and transport; pollution eg noise, effluent, gaseous discharge

*Socio-economic factors*: availability of skilled labour; financial support

2 **Understand factors affecting the selection of a chemical process**

*Process* factors: raw materials (availability, purity, costs, transport); yield (main products, co-products, waste materials); time factor (relative rates, balance of yield versus rate); operating conditions (costs, benefits in relation to yield and rate for chosen route); sustainability (carbon footprint)

*Quality of product*: ease of separation; purification; side products; quality control

*Other products*: co- and side-products (ease of separation, possible uses); transport

*Environmental Protection Act*: control and monitoring of effluents; safe disposal of waste products; the possible effects of operating the process on the immediate environment of the plant

*Safety aspects*: risk analysis for complete process; COSHH assessment

3 **Understand the physico-chemical aspects of an industrial process**

*Energetic factors*: energy requirements; energy flow; heat transfer

*Equilibrium factors*: equilibrium yield; operating conditions: balance of yield versus operating conditions; kinetic factors

*Kinetic factors*: factors affecting rate; choice of catalyst; reaction route; reaction conditions

*Separation and purification*: principles of phase equilibria underlying distillation; solvent extraction; chromatography; crystallisation/evaporation; scale eg research and development, pilot scale, plant scale

*Transfer of materials and resources*: water; raw materials; products; energy

4 **Understand the chemistry of the industrial process**

*Choice of reaction*: possible reaction pathways; reagents; reasons for selection

*Mechanism of reaction*: evaluation of mechanism for each stage

*Reaction conditions*: effect of temperature; effect of pressure; effect of catalyst; effect of other conditions on product and yield

*Yield*: of all possible pathways; factors affecting yields

*Separation/purification*: description of techniques used; evaluation of the effect on yield and quality of product

*Use and recycling of co-products*: separation; use; recycling; commercial value

## Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand factors affecting the location of a chemical plant | 1.1 explain how factors influence the choice of location<br>1.2 assess the relevance of transportation costs and explain the importance of available resources<br>1.3 review the effect of an environmental audit on the planning process<br>1.4 explain the relevance of socio-economic issues |
| LO2 Understand factors affecting the selection of a chemical process | 2.1 explain the relevance of process factors to a chemical process<br>2.2 explain the importance of the quality of the product<br>2.3 explain the importance of co- and side-products on the overall profitability of the process<br>2.4 assess safety aspects and discuss measures required for compliance with the Environmental Protection Act |
| LO3 Understand the physico-chemical aspects of an industrial process | 3.1 explain how energetic, equilibrium and kinetic factors influence the selected industrial process<br>3.2 explain the principles of separation and purification used in the process<br>3.3 explain the impact of the transfer of materials used in the process |
| LO4 Understand the chemistry of the industrial process | 4.1 justify the choice of reaction and identify the mechanism of each stage and its relation to the reaction conditions<br>4.2 explain the factors affecting yields including those of alternative pathways<br>4.3 describe the processes of separation and purification and their influence on the overall yield of product achievable<br>4.4 explain the potential uses and commercial values of the principal and co-products |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 2: Organic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 9: Inorganic Chemistry of Crystal Structures and Transition Metal Complexes*
- *Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds*
- *Unit 11: Physical Chemistry of Spectroscopy, Surfaces and Chemical and Phase Equilibria*.

## Essential requirements

## Delivery

Delivery must encourage learners to reflect on all aspects of the selected industrial process and to develop an awareness of business, socio-economic, health and safety and environmental considerations.

## Assessment

Learners must select an industrial process with guidance from tutors. It is envisaged that learners will build up a comprehensive and detailed case study of the process covered. They must demonstrate the ability to synthesise and apply concepts developed in the core units to the process.

Learners should also show an awareness of business, environmental, health and safety and socio-economic factors affecting the chemical industry.

## Resources

Ideally the primary resource for this unit is the learner's place of employment or other local chemical industry plant. If learners are not using their own place of employment, then appropriate visits are essential. In addition, museum visits to, for example the Science Museum or the Catalyst Museum, would be beneficial.

## Employer engagement and vocational contexts

Learners will benefit from visits to industrial chemistry sites to observe manufacturing practice.

# Unit 15: Biochemistry of Macromolecules and Metabolic Pathways

| | |
|---|---|
| Unit code: | F/601/0217 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

This unit enables learners to develop practical skills and examine the chemical characteristics of amino acids, monosaccharides, nucleotides and fatty acids. These are used to develop an understanding of the structure and function of related biological macromolecules.

## Unit abstract

Biochemistry deals with the chemistry of those molecular substances that occur in living organisms in terms of their structure and the processes in which they are involved. It is a key element in many scientific areas including medicine, pharmacology, genetics and biotechnology.

Learners will examine how biological systems comprise macromolecules which are derived from building block molecules such as amino acids, sugars, nucleosides and fatty acids. They will develop an appreciation of how the structure and properties of macromolecules are determined by the chemical structure and functional group chemistry of the building block molecules. The structure of macromolecules, including proteins, polysaccharides, nucleic acids and lipids, are examined with a view to relating them to key biological functions such as enzyme metabolism or protein biosynthesis.

The unit will also enable learners to understand the key features of principal metabolic pathways and their relationship to each other. For example, they will develop an appreciation of the role played by gluconeogenesis in overcoming irreversible steps in glycolysis.

Learners will have the opportunity to develop a range of basic practical skills by carrying out scientific investigations in the laboratory that involve measurement, separation and purification, as related to the above topics.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the chemical principles that apply to the structures of biological building block molecules

2 Understand the structures of biological macromolecules and the relationships to biological functions

3 Understand the features of and links between the major metabolic pathways

4 Be able to use biochemical practical skills and cognate techniques.

# Unit content

1 **Understand the chemical principles that apply to the structures of biological building block molecules**

*Amino acids*: functional group chemistry, acidic and basic properties, isoelectric points; chemical structure; side chain types and classification; optical isomerism; D and L classification; essential amino acids

*Monosaccharides*, *aldoses and ketoses*: functional group chemistry; reducing properties; reactivity of glycosidic hydroxyl groups; chemical structure; cyclic structure formation; $\alpha$ and $\beta$ terminology; optical isomerism

*Nucleosides and nucleotides*: nitrogen bases; sites of attachment of sugar residues

*Fatty acids*: saturated; unsaturated; essential fatty acids

2 **Understand the structures of biological macromolecules and the relationships to biological functions**

*Protein structure*: primary (planar nature of the peptide bond and dihedral angles); secondary (helix and $\beta$ sheet as a consequence of dihedral angles and hydrogen bonding); tertiary (types of intramolecular stabilising bonds; structure and properties of globular and fibrous proteins); quaternary eg haemoglobin

*Enzymes*: relationship between structure and function; enzymes as biological catalysts (active site structure, substrate binding, strain and specificity); properties of enzymes ($pH_{opt}$, $T_{opt}$, $V_{max}$, $K_m$); denaturation; enzyme inhibition limited to competitive and non-competitive; allosteric enzymes; collagen as a structural protein (role of glycine and praline, triple helix structure, fibril formation)

*Polysaccharides*: glycogen; starch; cellulose; relationship between storage polysaccharides and shape due to $\alpha$ glycosidic links; importance of branching; structural polysaccharides as a result of glycosidic links; enzymic hydrolysis of polysaccharides as a result of $\beta$ glycosidic links; enzymic hydrolysis of polysaccharides as a source of monosaccharides and energy

*Nucleic acids*: structure of a strand of deoxyribonucleic acid (DNA); double helix and the role of hydrogen bonding; types of ribonucleic acid (RNA); outline of protein biosynthesis

*Phospholipids*: lipids as exemplified by triglycerides and phospholipids; phospholipids in membrane formation; effect of saturated to unsaturated fatty acid ratio on membrane fluidity

3 **Understand the features of and links between the major metabolic pathways**

*Main metabolic pathways*: glycolysis; fermentation; electron transport; fatty acid β oxidation; gluconeogenesis; fatty acid synthesis

*Processes controlling metabolism*: free energy change; relationship between metabolism and free energy change; equilibrium; metabolic flux

*Irreversible steps*: irreversibility in terms of free energy changes; reverse of pathways as different chemical steps

*Control of glycolysis and gluconeogenesis*: factors that control catabolic pathways; factors that control anabolic pathways; phosphofructokinase (PFK1)

4 **Be able to use biochemical practical skills and cognate techniques**

*Protein separation*: methods used to separate or purify proteins eg gel filtration chromatography, ion exchange chromatography, affinity chromatography, polyacrylamide gel electrophoresis (PAGE)

*Determination of unknown concentrations*: selected biological molecules eg determination of concentrations of glucose, an amino acid or bovine serum albumin by colorimetry

Determination of enzyme characteristics: characteristics eg specific activity, $pH_{opt}$, $T_{opt}$, $V_{max}$, $K_m$, type of inhibition

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the chemical principles that apply to the structures of biological building block molecules | 1.1 explain the principal properties and classification of amino acids<br>1.2 explain the principal properties and classification of monosaccharides, aldoses and ketoses<br>1.3 explain the principal properties and classification of nucleosides and nucleotides<br>1.4 explain the principal properties and classification of fatty acids |
| LO2 Understand the structures of biological macromolecules and the relationships to biological functions | 2.1 discuss the differences in protein structure at primary, secondary and tertiary level between globular and fibrous proteins<br>2.2 explain the structure, catalytic function and characteristic properties of enzymes<br>2.3 review the major features of storage and structural polysaccharides<br>2.4 outline briefly the roles of the nucleic acids in protein biosynthesis with reference to the structural differences between DNA and different types of RNA<br>2.5 explain the structural features and properties of phospholipids that enable them to form membranes |
| LO3 Understand the features of and links between the major metabolic pathways | 3.1 summarise the function of the main metabolic pathways and the relationships between them<br>3.2 review the processes that control metabolic pathways<br>3.3 explain the apparent irreversible steps in glycolysis and the role of gluconeogenesis in overcoming them<br>3.4 explain the control of glycolysis and gluconeogenesis exhibited by phosphofructokinase (PFK1) |
| LO4 Be able to use biochemical practical skills and cognate techniques | 4.1 plan types of protein separation in terms of the theory and practice involved<br>4.2 carry out a separation and purification of protein from a simple mixture, using safe practices<br>4.3 determine experimentally the concentration of an unknown biological molecule, using safe practices<br>4.4 determine experimentally the characteristics of an enzyme, using safe practices |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 6: Analysis of Scientific Data and Information*.

## Essential requirements

## Delivery

Throughout the unit chemical structures must be used wherever possible. For learning outcome 1, learners must appreciate the differences between D and L isomers, as well as alpha and beta anomeric structures.

For learning outcome 2, for the structure of DNA, nitrogen bases should be represented by the letters ATCG.

For learning outcome 3, awareness of the links between pathways is essential.

For learning outcome 4, learners must cover three types of protein separation in terms of the theory and practice involved.

## Assessment

For learning outcome 1, learners must demonstrate an ability to represent chemical structures of compounds with one chiral centre in 2D and 3D forms as well as their knowledge of the fundamental principles of building block molecules. There should be an appreciation of the biochemical significance relating to functional group(s) within these molecules.

For learning outcome 2, learners must be able to show how the structure of the biological macromolecules enables them to perform the functions they are involved in. Again, particular emphasis should be placed on the chemistry underlying functions such as the catalytic activity of enzymes or the role of nucleotides in protein synthesis.

Evidence for learning outcome 3 needs to detail the biochemical reactions involved in the major metabolic pathways and recognise the importance of free energy ($\Delta G$) changes in these reactions. The relationship between the different pathways, especially glycolysis and gluconeogenesis, should be emphasised.

Learning outcome 4 requires learners to demonstrate practical skills and cognate techniques.

## Resources

Learners need access to well-equipped laboratory facilities to carry out practical investigations. Tutorial support, library and ICT resources are also required for learners to undertake independent research.

## Employer engagement and vocational contexts

Learners will benefit from visits to laboratories that are in engaged in investigations or research into biochemical processes. For example, medical laboratories, agri-food research and/or veterinary science. These facilities would enable learners to observe the application of biochemistry and biochemical techniques within a particular context.


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# Unit 16: Polymer Chemistry

| | |
|---|---|
| Unit code: | L/601/0415 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

This unit enables learners to gain an understanding of aspects of the structure, reaction mechanisms and polymer preparations. The properties, performance, behaviour and breakdown of types of polymer under a variety of conditions are also examined.

## Unit abstract

The commercial uses of polymers and composite polymers are limitless and are an essential aspect of everyday life. Supermarket plastic bags, contact lenses, packaging and insulation materials are just a few examples of polymers that are used almost daily.

The development of polymer science provides a classic example of systematic chemical innovation and progress. This unit builds on the knowledge and understanding of functional group chemistry and mechanisms and expands these to give an understanding of polymer science.

Polymerisation mechanisms are used to support different types of polymerisation techniques. This leads to an examination of structural features of polymers related to their polymeric properties and characteristics. The unit concludes by examining polymer performance together with conditions likely to cause failure in behaviour when polymers are used in extreme environments.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand polymerisation mechanisms and techniques

2 Understand the basic properties of polymers from their structural features

3 Understand the service performance and environmental behaviour of polymers.

# Unit content

1 **Understand polymerisation mechanisms and techniques**

*Free radical mechanisms*: initiator types; propagation; termination reactions eg vinyl polymers

*Reaction rates and degree of polymerisation*: deduction of general rate equations using the chemical equations generated for free radical mechanisms

*Step polymerisations*: uncatalysed and catalysed systems; degree of polymerisation; extent of reaction

*Ionic processes*: cationic; anionic; living polymer systems; Ziegler-Natta catalysts

*Ring opening processes*: lactams; epoxy systems

*Co-polymerisation technique*: reactivity ratios; Mayo-Lewis equation for determination of reaction rates

*Polymerisation techniques*: bulk solution; suspension; emulsion systems; kinetics of emulsion free radical systems eg bulk polymerisation of methyl methacrylate, suspension polymerisation of styrene, emulsion polymerisation of methyl methacrylate, preparation of polyesters, preparation of polyurethane

2 **Understand the basic properties of polymers from their structural features**

*Glass transition temperature*: relationship between polymer structure and glass transition temperature; tacticity; geometrical isomerism; branching; transparency; relationship between polymer properties and glass transition temperature; strength; stiffness; impact strength; ability to crystallise

Crystal structure of polymers and their relation to properties and uses: single crystal; spherulites; strain-induced crystallisation

*Creep strain and stress relaxation*: Maxwell and Kelvin-Voigt models

*Molecular mass*: number and weight averages; molecular mass distribution; effect on processing properties; calculations and determinations

*Mechanical properties*: strength; rigidity; moulding ability


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3 **Understand the service performance and environmental behaviour of polymers**

*Factors responsible for the degradation of polymers on processing and in service*: thermodynamic depolymerisation; oxygen uptake; free radical autocatalytic mechanisms; heat; ozone; fatigue; chemical attack; apply to appropriate examples eg natural rubber, polypropylene

*Common antidegradants*: theories of antidegradant action; chain breaking donor and chain breaking acceptor mechanisms

Environmental stress cracking: mechanisms; surface energy

Structure of polymers related to attack by common inorganic and organic chemicals: discussion of polar and non-polar polymers; use of solubility parameter data

*Environment*: effects of eg heat, light, chemical attack by water, oil, petrol, disinfectants

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand polymerisation mechanisms and techniques | 1.1 explain the mechanisms of free radical polymerisation and step polymerisations employing functional groups<br>1.2 deduce rate of equation for free radical and step polymerisations<br>1.3 explain the importance of ionic, step and ring opening polymerisation techniques in the development of new polymers<br>1.4 explain the importance of co-polymerisation techniques<br>1.5 use polymerisation techniques safely to produce small quantities of free radical and step polymers using standard laboratory apparatus |
| LO2 Understand the basic properties of polymers from their structural features | 2.1 relate the crystal structures and properties of polymers to their glass transition temperature<br>2.2 deduce the ability of a polymer to crystallise from its structural features<br>2.3 relate crystal structure to the properties and uses of polymers<br>2.4 use literature data to calculate creep strain and stress employing Maxwell and Kelvin-Voigt equations<br>2.5 calculate molecular mass averages and molecular mass distribution<br>2.6 relate molecular mass averages and molecular mass distributions to mechanical properties and processing behaviour |
| LO3 Understand the service performance and environmental behaviour of polymers | 3.1 discuss the factors responsible for the degradation of polymers on processing and in service<br>3.2 explain the action of common antidegradants<br>3.3 explain potential environmental stress cracking of polymers<br>3.4 explain the relation of polymer structure to attack by common inorganic and organic chemicals<br>3.5 perform experiments safely to investigate the influence of the environment on polymers |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 2: Organic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds*
- *Unit 11: Physical Chemistry of Spectroscopy, Surfaces and Chemical and Phase Equilibria*.

## Essential requirements

### Delivery

Polymerisation mechanisms must be discussed alongside typical techniques employed. Wherever possible, practical investigations must be undertaken.

Emphasis must be placed on relating structural features to the properties of polymers and to conditions relating to polymer failure.

### Assessment

Learners must prepare polymers using a variety of techniques, for example bulk polymerisation of methyl methacrylate, suspension polymerisation of styrene, emulsion polymerisation of methyl methacrylate, preparation of polyesters and preparation of polyurethane. These may all be prepared using standard laboratory equipment.

Learners must demonstrate their understanding of the basic properties of polymers from their structural features.

Published data can be used to calculate stress and strains from Maxwell and Kelvin-Voigt equations that describe creep strain and stress relaxation. Molecular mass averages must also be calculated.

Learners must undertake a practical investigation into the influence of the environment on stressed mouldings of polyethene and polycarbonate. (The term environment includes any gas, liquid or solid that may come into contact with the moulding.)

Learners must investigate the reactivity of common inorganic and organic chemicals on polar and non-polar polymers. Solubility parameter data must be used to predict the reactivity of inorganic and organic chemicals.

### Resources

Learners require access to a chemical laboratory. The use of typical rubber and plastics products would help to illustrate the effects of glass transition and crystallinity.

## Employer engagement and vocational contexts

Learners will benefit from visits to industrial laboratories particularly in the polymer sector. They should have the opportunity to gain experience of processing behaviour and the use of antidegradant systems and to see pilot scale and manufacturing scale plant in operation.

# Unit 17: Medicinal Chemistry

| | |
|---|---|
| Unit code: | R/601/0416 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

This unit enables learners to gain an understanding of the factors relating to drug structure and design, pharmacokinetics and pharmacodynamics and biochemical responses of drug treatment.

## Unit abstract

This unit develops principles of medicinal and clinical chemistry associated with drug design and structure together with biochemical aspects of drug action. Structure-activity relationships and computer-aided drug design are considered as aspects contributing to drug discovery and design. The role of combinatorial chemistry in drug synthesis is also considered.

Effectiveness of drug structures is assessed in relation to the role of enzymes and receptors as drug targets and the mechanisms by which they bind drugs. The unit develops the principles of pharmacokinetics and pharmacodynamics as a method of rationalising the evaluation of drugs in terms of route administration, metabolism, excretion and biochemical response.

The unit concludes by exploring the effect of selected chemicals on the body thus enabling learners to apply the principles established in the earlier parts of the unit.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the role of enzymes and receptors as drug targets

2 Understand the pharmacokinetic and pharmacodynamic behaviour of drugs

3 Understand the stages of drug discovery and design

4 Understand the role of biologically active molecules in biochemical systems.

# Unit content

1 **Understand the role of enzymes and receptors as drug targets**

*Drug targets*: enzymes; inhibitors (reversible, non-reversible, competitive, non-competitive); medicinal uses of enzyme inhibitors against micro-organisms, viruses and the body's own enzymes; receptors; classification of main receptor types; signal transduction systems

*Drug receptor binding interactions*: ionic bonding; hydrogen bonding; Van der Waals interactions; dipole-dipole interactions; covalent bonding; functional groups

*Enzyme inhibition*: competitive and non-competitive enzyme kinetics; Michaelis-Menton, Lineweaver-Burk plots

*Receptors*: receptor types; agonists; antagonists; tolerance and dependence; affinity; efficacy; potency

2 **Understand the pharmacokinetic and pharmacodynamic behaviour of drugs**

*Influence of route of administration on systemic toxicity*: pharmacokinetics and pharmacodynamics (absorption, distribution, metabolism, excretion, administration, dosing, drug interactions); relationships to toxicity tests; evaluation of the principles of pharmacological toxicity

*Drug metabolism*: metabolic sites; common pathways; factors affecting drug metabolism (dose level, routes of administration, sex related differences, age, disease, drug interactions, genetics)

*Methods of biological evaluation of drugs*: toxicity testing; evaluation of new drug substances; in vitro and in vivo evaluation of drugs, ligand binding; agonist and antagonist activity, tissue studies; formulation and chemical development; toxicity versus safety theoretical concepts

*Abnormal responses*: immune mechanisms; haptens; allergic reactions; activation and suppression of the immune and sensitising systems

3 **Understand the stages of drug discovery and design**

*Designing a new drug*: choice of disease, choosing a suitable drug target, finding a lead compound; screening natural products, development of existing drugs

*Structure-activity relationships*: identification of functional groups; potential binding sites; identification of pharmacophore; variation of substituents; quantitative structure-activity relationships (QSAR); partition coefficients, lipophilicity; computer-aided drug design

*Combinatorial chemistry*: basic concepts; advantages compared to traditional synthesis; design of syntheses; combinatorial libraries; outline of general techniques; solid support method, parallel synthesis, solution synthesis

4 **Understand the role of biologically active molecules in biochemical systems**

*Biologically active molecules*: development and action of the penicillins; penicillin antibiotic resistance; development and action of angiotensin converting enzyme (ACE) inhibitors; principles and examples of anticancer agents; antiviral drugs and acquired immune deficiency syndrome (AIDS) virus; cellular production and role of nitric oxide

*Clinical toxicology*: acute toxicity, chronic toxicity, teratogenic tests, reproduction tests, mutagenicity, chemical-induced illness

*Clinical toxicity*: risk assessment; hazard versus risk benefits

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the role of enzymes and receptors as drug targets | 1.1 explain the role of enzymes and receptors as drug target sites<br>1.2 explain drug-receptor binding interactions<br>1.3 distinguish between competitive and non-competitive enzyme inhibition<br>1.4 explain the relationship between receptors and drug affinity, efficacy and potency |
| LO2 Understand the pharmacokinetic and pharmacodynamic behaviour of drugs | 2.1 discuss the influence of route of administration on systemic toxicity<br>2.2 review pathways of drug metabolism<br>2.3 explain methods of biological evaluation of drugs<br>2.4 explain abnormal responses to drugs |
| LO3 Understand the stages of drug discovery and design | 3.1 discuss the issues for consideration when designing a new drug<br>3.2 explain the concepts of structure-activity relationships with respect to drug design<br>3.3 explain the role of combinatorial chemistry in drug synthesis and development |
| LO4 Understand the role of biologically active molecules in biochemical systems. | 4.1 discuss the development and role of selected biologically active molecules<br>4.2 explain clinical toxicological terms citing suitable examples<br>4.3 explain the principles of clinical toxicity |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 2: Organic Chemistry*
- *Unit 10: Organic Chemistry of Aromatic and Carbonyl Compounds*
- *Unit 15: Biochemistry of Macromolecules and Metabolic Pathways*.

## Essential requirements

## Delivery

The unit should be delivered in a manner that emphasises the chemical principles involved in drug action and design. Wherever possible chemical structures or part structures in the form of functional groups, rather than descriptive terminology, must be used to illustrate concepts such as binding, drug metabolism and structure-activity relationships. Throughout the unit specific examples of drugs or case studies must be used to illustrate principles and conceptual aspects of the unit content.

## Assessment

Where possible, assessments must be based on the application of principles to specific examples of drugs. Learners must be encouraged to undertake literature searches in relation to the development, testing and action of named drugs. Structure-activity relationships and enzyme kinetics must be assessed in a quantitative as well as a qualitative manner.

## Resources

Learners will need access to library and information technology resources, tutorial and technical support, molecular models and laboratory facilities.

## Employer engagement and vocational contexts

Learners will benefit from visits to pharmaceutical laboratories to observe research and development procedures in operation.

# Unit 18: Atomic and Nuclear Physics for Spectroscopic Applications

Unit code: Y/601/0417

Level: 4

Credit value: 15

## Aim

This unit provides an understanding of the underlying atomic and nuclear physics involved in the processes of spectroscopy and matter analysis.

## Unit abstract

Understanding the structure of compounds on an atomic and molecular level is an important part of modern analytical chemistry. This can be carried out directly, by viewing individual atoms with a scanning tunnelling electron microscope, or indirectly through methods such as infrared spectroscopy. This unit aims to develop learners' knowledge and understanding of the structure of the atom gained in the core units and extend it so that learners gain an understanding of the principles of spectroscopy and matter analysis.

Starting with an overview of quantum theory and the particle-wave nature of matter, the unit covers the key processes behind electron transitions. This directly leads to an understanding of electromagnetic wave spectroscopy, specifically optical and ultraviolet. Other wavelengths involve different processes within the atom and infrared, x-ray and gamma ray spectroscopy are explored in turn.

The use of charged particles in matter analysis is examined by exploring the interaction between charge and electromagnetic fields. This leads into an examination of the construction and operation of the electron microscope and the mass spectrometer. The unit concludes with an overview of how the nucleus of the atom is being used increasingly in analytical chemistry, through the use of neutron scattering and nuclear magnetic resonance.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the behaviour of matter in an atomic scale

2 Understand spectroscopic methods that use electromagnetic waves

3 Understand matter analysis methods that use charged particles

4 Understand spectroscopic methods that use the nucleus of an atom.

# Unit content

1 **Understand the behaviour of matter in an atomic scale**

*Quantum theory*: Planck's model of radiation; the photoelectric effect; Einstein's solution to the photoelectric effect; quanta and photons

*Particle-wave duality*: de Broglie's hypothesis; particle versus radiation wavelengths eg electrons vs light; experimental evidence eg Compton scattering, electron diffraction; Heisenberg uncertainty principle

*Model of the atom*: concept of spin; magnetic moment; Bohr's model of hydrogen; overview of the quantum mechanical model; quantum numbers; electron orbitals

*Electron transitions*: Pauli exclusion principle; selection rules for transitions; Hund's rules

2 **Understand spectroscopic methods that use electromagnetic waves**

*Optical spectroscopy*: emission spectra eg Balmer series of hydrogen; absorption spectra; continuous spectra; fine structure; effect of external magnetic fields on spectra; the use of optical spectra in determining sample composition

*High energy spectroscopy*: transitions involving ultraviolet radiation; ultraviolet fluorescence spectrometers; sources of x-rays; synchrotron radiation; Bragg's law; x-ray diffraction of metals and crystals; sources of gamma rays; Mössbauer absorption spectroscopy

*Infrared spectroscopy*: simple harmonic motion; resonance; modes of vibration; quantisation of vibration; infrared spectra for common organic compounds eg alcohols

3 **Understand matter analysis methods that use charged particles**

*Electromagnetic fields and charge*: description of electromagnetic fields; effects of electromagnetic fields on charged particles; particle acceleration; energy gained in a field

*Electron microscopes*: electron sources; thermionic emission; field emission; electron diffraction; transmission electron microscopes; tunnelling electron microscopes; resolution limits

*Mass spectrometers*: structure of a mass spectrometer; mode of operation of mass spectrometers; use of mass spectra in determining relative atomic mass; use of mass spectra in determining molecular structure

4 **Understand spectroscopic methods that use the nucleus of an atom**

*Nuclear structure*: nucleons; nuclear shell structure; magic numbers; strong nuclear force; nuclear stability; modes of decay; neutron emission

*Neutron spectroscopy*: neutron sources; neutron energy levels; neutron detectors; neutron diffraction; health risks associated with using neutrons

*Nuclear magnetic resonance*: nucleon spin; nuclear magnetic moment; nuclear energy levels; nuclear magnetic resonance condition; Nuclear Magnetic Resonance (NMR) spectroscopy

## Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the behaviour of matter in an atomic scale | 1.1 explain the relationship of quantum theory to the atomic structure of matter<br>1.2 evaluate the particle-wave nature of the components of atoms for given energy levels<br>1.3 justify the use of quantum theory in the model of an atom<br>1.4 evaluate electron transitions for hydrogen-like atoms |
| LO2 Understand spectroscopic methods that use electromagnetic waves | 2.1 compare the optical spectra of elements to their electronic structure<br>2.2 evaluate the lattice structure of a specific metal using high energy spectroscopy<br>2.3 discuss the molecular structure and vibrational modes of an organic compound with reference to infrared spectra |
| LO3 Understand matter analysis methods that use charged particles | 3.1 explain the effects of electromagnetic fields on charged particles<br>3.2 explain the operation and applications of electron microscopy<br>3.3 determine the molecular structure of compound using data gathered via mass spectroscopy |
| LO4 Understand spectroscopic methods that use the nucleus of an atom | 4.1 explain the nuclear structure of an atom<br>4.2 compare the use of neutron spectroscopy in matter analysis against electromagnetic wave forms of spectroscopy<br>4.3 explain the operation of an imaging device that uses nuclear magnetic resonance |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 2: Organic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 12: Analytical Chemistry*
- *Unit 13: Environmental Chemical Analysis*
- *Unit 24: Nuclear Chemistry*.

## Essential requirements

## Delivery

Where possible, the unit must be delivered using a combination of theory and practical experiments. Access to mass spectrometers, NMR machines etc could be achieved through arranged visits to analytical, research or medical facilities. The content is sufficiently flexible that this can be biased towards the specialist knowledge of the member of staff concerned as long as the basic understanding of the links are made between the chemistry and the theoretical physics. A strongly mathematical approach should be avoided, although the basic formulae such as $E=hf$ and the key physics behind the processes, such as spin and magnetic moments, must be covered. There are opportunities for learners to research and summarise evidence for themselves.

## Assessment

Learning outcome 1 involves the fundamental physics behind the principles of spectroscopy and matter analysis. Evidence may be integrated with evidence from learning outcomes 2 and 3. Evidence should contain example calculations involving the key formula involved.

Learning outcomes 2 and 3 involve the application of the knowledge and principles from learning outcome 1 to electromagnetic wave spectroscopy, electron microscopes and mass spectrometers. The evidence should include case studies or experimental studies, where appropriate.

Learning outcome 4 involves the fundamental physics behind the use of neutrons in matter analysis and nuclear magnetic resonance spectroscopy.

## Resources

This unit requires that learners can access suitable optical spectrometers and spectral sources (at least hydrogen and sodium lamps). Ideally, electron tubes to demonstrate electromagnetic deflection of charged particles and particle diffraction should be available. A demonstration of quantum theory in practice and a measurement of Planck's constant can be carried out via the use of LEDs.

## Employer engagement and vocational contexts

Learners will benefit from visits to industrial and research facilities to observe practical applications of spectrophotometers.

# Unit 19: Environmental Monitoring and Analysis

Unit code: Y/601/0238

Level: 5

Credit value: 15

## Aim

This unit provides learners with an understanding of natural environmental cycles and the influence of pollutants on ecosystems. The sources and effects of environmental pollutants together with techniques of sampling and chemical analysis are examined.

## Unit abstract

The analysis of the natural environment and the impact of human activity on it are central to this unit. Through studying this unit learners will learn about the environment close to where they live and work, as well as the global systems we all depend on.

Learners will learn how the balance of the natural environment relies on transfer mechanisms to cycle and purify its components. The complex nature of the interactions involved and the influence of pollutants on ecosystems are covered.

The importance of fossil fuel combustion as a source of pollution is studied and the effects on ecosystems assessed.

Following the initial introduction to the natural environment, and the potential pollutants within it, learners will plan and carry out an analysis of appropriate material from a selected site. Learners will assess the suitability of a sampling site and select material for analysis and analytical techniques under guidance from their tutor. This practical study allows for an iterative approach to the development of suitable sampling and analytical procedures.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand how biogeochemical cycles result in the transfer of substances between components of ecosystems

2 Understand the sources and effects of environmental pollutants

3 Be able to apply sampling methods appropriate to an analyte

4 Be able to determine the concentration of analytes in samples.

# Unit content

1 **Understand how biogeochemical cycles result in the transfer of substances between components of ecosystems**

*Abiotic components of biogeochemical cycles*: hydrosphere; lithosphere; atmosphere; soil structure and composition; atmospheric transport; aquatic systems

*Mechanisms of substance transfer*: water cycle; nutrient cycles (carbon, nitrogen, oxygen, phosphorus, sulfur); non-nutrient transfer; by organic species eg PCBs, DDT, hydrocarbons; metals eg lead, cadmium, mercury

*Influences on substance cycling*: abiotic components of ecosystems; physical properties and composition of aquatic habitats, soil and air; biotic components of ecosystems; feeding, uptake from soil, assimilation, excretion, decomposition

2 **Understand the sources and effects of environmental pollutants**

*Sewage treatment*: composition of raw sewage; role and effect of primary, secondary and tertiary treatment processes; typical process equipment

*Industrial sources of pollutants*: sources of water, air and soil pollutants eg petrochemical processing, power generation, mining, manufacturing

*Agricultural sources of pollutants*: fertilisers; herbicides; pesticides; animal wastes; methane; cleaning agents

*Fossil fuel combustion products*: gas, petrol, oil and coal combustion products; environmental impact of carbon, nitrogen and sulfur oxides; photochemical smog

*Effect of pollutants on ecosystems*: toxicity; bioconcentration; biodiversity effects; viral and bacterial pathogens; acidification; greenhouse effect

3 **Be able to apply sampling methods appropriate to an analyte**

*Selection of sampling location*: appropriate site eg local, field trip, industrial, agricultural; type of pollutant (water, soil, air); accessibility; health and safety considerations

*Design of sampling protocol*: protocol related to sample type eg water volume, flow, time, container volume, storage and stabilisation, analyte mobility, analyte stability

*Quality control*: planning for sampling; random sampling; internal standards

*Environmental sampling*: implementation of sampling protocol; iterative cycle for improvement

 

4 **Be able to determine the concentration of analytes in samples**

*Planning*: selection of analytical technique related to analyte eg pre-treatment, extraction, dissolution, spectrometry, chromatography, titration, electrochemical, voltammetry, fluorescence, chemiluminescence

*Determination of analyte concentration*: implementation of planned analysis; evaluation of results; alteration of plan; repeat of sampling and analysis

*Report on analytical procedure*: accuracy; reliability; statistical analysis; suggestions for future work

*Maximum permitted levels*: related to selected analyte eg total organic carbon, nitrate, nitrite, ammonia, biochemical oxygen demand, pH, particulates, suspended solids, heavy metals

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand how biogeochemical cycles result in the transfer of substances between components of ecosystems | 1.1 discuss the abiotic components of biogeochemical cycles<br>1.2 explain mechanisms by which substances are transferred between environmental components<br>1.3 explain the abiotic and biotic factors that influence the cycling of substances |
| LO2 Understand the sources and effects of environmental pollutants | 2.1 explain the key stages in sewage treatment<br>2.2 analyse industrial processes as sources of pollutants<br>2.3 compare agricultural processes as sources of pollutants<br>2.4 discuss the environmental impact of fossil fuel combustion products<br>2.5 assess the effects of selected pollutants on ecosystems |
| LO3 Be able to apply sampling methods appropriate to an analyte | 3.1 select a suitable location for sampling<br>3.2 design a sampling protocol for specified analytes at a location<br>3.3 implement quality control criteria for a sampling regime<br>3.4 carry out appropriate environmental sampling, using safe practices |
| LO4 Be able to determine the concentration of analytes in samples | 4.1 plan analyses appropriate for a specified analyte<br>4.2 determine the concentration of an analyte in a sample<br>4.3 report on the accuracy of the results of an analytical procedure<br>4.4 relate the concentration of an analyte to the maximum permitted levels |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 2: Organic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 4: Chemical Laboratory Techniques*
- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 12: Analytical Chemistry*
- *Unit 13: Environmental Chemical Analysis*
- *Unit 20: Environmental Management and Conservation*.

## Essential requirements

## Delivery

Learning outcome 1 covers the complexity of the natural environment and natural material cycles. The nature of soil types including acid-base character and ion exchange effects must be stressed.

Learning outcome 2 can be achieved through case studies and industrial visits. Flow diagrams for the selected industrial or agricultural process, with quantification of the potential pollutant and waste flows, could be produced before the visit to provide a greater appreciation of the emphasis on environmental protection in modern industrial processes. Learners in industry must be encouraged to investigate environmental protection measures at their place of work.

Learning outcomes 3 and 4 are essentially practical and could be delivered using a project-based approach. The intention is to follow a given analysis from selecting an appropriate site through planning sampling regimes to applying suitable chemical analysis to provide an accurate and reproducible result. If group work is used, tutors must ensure that each individual learner provides sufficient evidence of meeting the assessment criteria on an individual basis. Learners may be guided in selecting an appropriate analyte depending on the analytical facilities available at the centre.

Visits to commercial analytical laboratories would be useful in allowing learners to observe quality control systems in practice and appreciate the issues raised by a delay between sampling and analysis.

## Assessment

Learning outcome 1 involves the general principles of biogeochemical cycles and as with learning outcome 2, evidence could be generated from case studies.

Learning outcomes 3 and 4 involve planning and practical work and could be suitable for group or individual projects.

## Resources

Learners will need access to appropriate laboratory facilities and technical support. The apparatus and instrumentation required will depend on local resources and the analytical methods chosen. Suitable local sampling sites should be identified to support laboratory work. General library facilities, including internet access, will also be needed. Relevant periodicals would be beneficial for resource-based research work.

## Employer engagement and vocational contexts

Learners would benefit from visits to industrial settings where effluent treatment and environmental monitoring can be observed. Visits would enable learners to appreciate how reducing environmental impact is central to modern industrial design and processing.

# Unit 20: Environmental Management and Conservation

Unit code: K/601/0289

Level: 5

Credit value: 15

## Aim

This unit reviews environmental issues such as conservation sites, recycling and land reclamation. Learners gain an understanding of the causes and effects of pollution, global environmental issues, renewable energy, and the work of environmental pressure groups.

## Unit abstract

Learners will have the opportunity to explore environmental issues in their own community. To make the most of this, learners may visit Sites of Special Scientific Interest, recycling facilities, brownfield land that is being re-used, and local industry. Learners will investigate the origins and effects of pollutants and study how pollution may be controlled.

Evidence for human impact on global climate change and international initiatives to combat the effects through carbon trading will be explored. The work of environmental pressure groups in bringing environmental issues into the public domain will be investigated.

Finally, learners will study legislation, particularly in relation to waste, in order to gain an understanding of the quality of the information that government provides to business. Case studies will be used to assess the effectiveness of environmental management systems.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the major strategies for conservation of resources

2 Understand the causes, effects and the control of pollution

3 Understand global environmental issues

4 Understand how environmental legislation may be put into practice.

# Unit content

1 **Understand the major strategies for conservation of resources**

*Statutory designations*: designated areas eg Sites of Special Scientific Interest (SSSI) (biological and geological), Special Areas of Conservation (SAC), Ramsar sites, national and local nature reserves and Marine Protected areas; establishment of designated areas; design of designated areas; development of designated areas; management of designated areas

*Processes*: guidelines for selection eg geological conservation review, notification, consultation and confirmation with respect to Sites of Special Scientific Interest, identification of SACs in line with Habitats Directive, government approval of SACs, adoption of UK list of SACs by European Union, criteria in Ramsar convention

*Resource recycling*: recycling eg glass, aluminium, paper, wood, plastic; the strategies employed by local councils; packaging waste regulations eg Producer Responsibility Obligations (Packaging Waste) Regulations 2007; compliance schemes for relevant packaging waste regulations eg Valpak

*Land resource management*: relevant legislation eg Planning and Compulsory Purchase Act 2004; the role of the spatial planning system in conserving the natural environment and delivering high quality environmentally sustainable development; the technical and management issues in the remediation and use of brownfield land; local authority registers of contaminated land

2 **Understand the causes, effects and the control of pollution**

*Pollutants*: common air pollutants eg sulfur oxides ($SO_x$), nitrogen oxides ($NO_x$), low level ozone, benzene, 1,3 butadiene, lead, PM10; sources of the common air pollutants eg transport, energy use, manufacturing industry; List 1 aquatic pollutants from the Dangerous Substances Directive; sources of List 1 aquatic pollutants; agricultural aquatic pollutants eg silage run off, nitrates, phosphates, slurry, sheep dip

*Effects on organisms within an ecosystem*: eutrophication; increase in chemical oxygen demand; effects of sulfur dioxide on vegetation

*Current relevant strategies*: Environment Act 1995; National Air Quality Strategy; National Air Quality Standards and Objectives; National Atmospheric Emissions Inventory; European Pollutant Emission Register (EPER); Environmental quality standards; river ecosystem classifications bio-monitoring; indicator species; keystone species

*Control methods*: legislation eg Integrated Pollution Prevention Control (IPPC), The Water (Prevention of Pollution) (Code of Good Agricultural Practice) (England) Order 2009; identification of areas at risk eg Air Quality Management Areas (AQMA), Nitrate Vulnerable Zones; best available techniques; best available techniques reference documents; specific techniques eg flue gas desulfurisation

3 **Understand global environmental issues**

*Climate change*: greenhouse gases and their atmospheric effects; economic and social consequences of global warming; global initiatives eg the Kyoto Treaty, Copenhagen Climate Summit; ozone depletion and the Montreal protocol

*Carbon trading*: EU Emission Trading (ETS) Scheme; Clean Development Mechanism; carbon markets

*Energy security*: peak oil; biofuels; carbon capture and storage; clean coal; nuclear power, renewable energy sources; energy security; the UK Low Carbon Transition Plan

*Pressure groups*: national or international eg Friends of the Earth, World Wide Fund for Nature (WWF), Greenpeace

*Global campaigns*: campaign of topical interest eg carbon footprint, lifecycle analysis, food miles, sustainable transport, saving the rainforests, limiting ozone depletion (Montreal Protocol)

4 **Understand how environmental legislation may be put into practice**

*Legislation*: UK/EU eg the Environmental Protection Act 1990, Environmental Permitting Regulations 2007, Environmental Liability Directive, Waste Framework Directive, Batteries Directive

*Operation of environmental permitting regulations*: managing activities; suitable environmental management system; use of competent persons; accident management plan; permit conditions/rules; waste acceptance; point source emissions to air, water and land; fugitive emissions; odour; noise and vibration; monitoring; records; reporting/notification

*Waste management*: environmental permitting regime (England and Wales) eg pollution prevention and control, waste management licenses, waste carriers and broker registrations, water discharge consents, groundwater authorisations; waste management duty of care; Pollution Prevention Guidelines

*Environmental management systems*: structured and documented environmental management systems (EMS) to manage environmental performance and responsibilities; EMS certification, ISO 14001; the EU Eco-Management and Audit Scheme (EMAS); BS 8555 (a British Standard for Small and Medium Enterprises (SMEs))

# Learning outcomes and assessment criteria

| Learning outcomes | Assessment criteria for pass |
|---|---|
| **On successful completion of this unit a learner will:** | **The learner can:** |
| LO1 Understand the major strategies for conservation of resources | 1.1 discuss current national and international statutory designations protecting the UK's natural environment<br>1.2 explain the processes involved in the establishment of a designated area for conservation<br>1.3 discuss how the UK reduces waste and promotes recycling<br>1.4 discuss issues involved in land resource management |
| LO2 Understand the causes, effects and the control of pollution | 2.1 discuss pathways of named pollutants from source to receptor<br>2.2 assess the effects of a named pollutant on organisms within an ecosystem<br>2.3 discuss strategies used for monitoring pollutants in water and air emissions<br>2.4 assess methods for controlling pollution |
| LO3 Understand global environmental issues | 3.1 evaluate evidence for the contribution of human activities to climate change<br>3.2 review international carbon trading<br>3.3 discuss environmental aspects of the UK's energy security policy<br>3.4 assess the role of an environmental pressure group in a global environmental campaign |
| LO4 Understand how environmental legislation may be put into practice | 4.1 review current UK/EU/ environmental protection legislation<br>4.2 explain operation of the Environmental Permitting Regulations<br>4.3 explain how businesses comply with their duty of care for waste management<br>4.4 assess, using case studies, the effectiveness of using an environmental management system |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 12: Analytical Chemistry*
- *Unit 13: Environmental Chemical Analysis*
- *Unit 19: Environmental Monitoring and Analysis*
- *Unit 21: Quality Assurance and Quality Control*.

## Essential requirements

## Delivery

Current legislation and initiatives are mentioned in the unit content but these must be replaced by suitable alternatives if they become out of date. In all cases the latest legislation must be used. Where possible, learners should visit sites and organisations and the use of visiting speakers is strongly encouraged.

Learning outcome 1 covers Sites of Special Scientific Interest, recycling and waste minimisation and reclamation of brownfield land. Ideally, learners should visit a Site of Special Scientific Interest, a brownfield site that is being put to a new use and a council recycling facility. Input from experts at the site will deepen learner understanding. If this is not possible, learners must be encouraged to find out about relevant sites in their area.

Learning outcome 2 has a particularly wide scope, which has been limited to consideration of air and water (and not land). It could be delivered by introducing the general content and then focusing on issues of particular relevance to the centre's location. Centres in a predominantly rural area, for example, may wish to concentrate on aquatic agricultural pollution, such as nitrate pollution. Other centres in industrial areas may choose to consider the effects of sulfur dioxide in great detail.

For learning outcome 3, there is a great deal of information about global warming available. One strategy would be to select a number of documents from a variety of sources for learners to study. This would allow them to evaluate the information in the evidence, and also the quality of the evidence, and to decide whether they would need more/different evidence to be able to draw firm conclusions. Possible strategies for the UK's energy security policy must be discussed and the Government's preferred options identified. The environmental implications of alternative forms of energy must be explored. This could involve analysis of numerical data.

Learning outcome 4 gives learners the chance to explore the value of Netregs, the government website dealing with environmental legislation. This will support the first three assessment criteria.

## Assessment

For learning outcome 1, learners may look at the current national and international statutory designations protecting the UK's natural environment in general but go into more depth to address the unit content in relation to the processes involved in setting up one of these sites. Where possible, learners should visit a local site. Learners must address the unit content in outlining the reclamation of brownfield land, using a local case study where possible.

For learning outcome 2, the focus needs to be limited to allow learners to gain a depth of understanding. Particular pollutants need to be selected with reference to the pathways from source to receptor. Pollutants need to be chosen carefully in order to be relevant and to allow learners to select good quality information. In discussing strategies used for monitoring pollutants, emphasis must be on the overview of data taken by Government agencies and local authorities, rather than on specific analytical techniques. Methods of controlling one or more pollutants must be covered. This must involve specific pollution abatement techniques and also the supporting legislation. Once again, the focus could be different, for example industrial or agricultural.

For learning outcome 3, learners could source articles about global warming. They could assess the quality of the articles, the quality of the evidence and identify further desirable work in this area. Learners must review the nature and extent of international carbon trading. Government information on future energy supplies is available. The focus is not only on the nature of the energy security policy but the implications for the environment. Learners must identify a high profile global campaign, which a pressure group is/has been involved with and assess the role of the pressure group in that campaign.

Learning outcome 4 gives learners scope to present material on legislation that they have obtained from Netregs or other sources. Learners must assess the features of an environmental management system and how it operates. Additionally, case study information from industry is required about the effectiveness of using an environmental management system. ISO 14000 is the most common environmental management system. However, learners may write about the effectiveness of others if they have suitable industrial input.

## Resources

Learners must have access to real case studies and/or real-life situations. Access to current legislation and initiatives is also essential.

## Employer engagement and vocational contexts

Learners would benefit from visiting Sites of Special Scientific Interest, recycling facilities and reclaimed land. The causes, effects and control of pollution may be assessed in a local context. It is essential to have industrial input to assess the effectiveness of using an environmental standard. Guest speakers from industry and other groups would enhance delivery.

# Unit 21: Quality Assurance and Quality Control

Unit code: F/601/0301

Level: 4

Credit value: 15

## Aim

This unit reviews quality assurance and quality control measures. Learners are provided with an understanding of quality control and assurance procedures, methods of expressing quality and the benefits of accreditation.

## Unit abstract

Laboratories carry out analysis for a number of reasons. For example, some laboratories support a manufacturing process while others are contracted by external organisations to carry out analysis. Analytical data must be sufficiently accurate for the customer to use. All laboratories have measures in place to ensure that results are fit for purpose.

In this unit learners will gain an understanding of the possible sources of inaccuracy within analytical processes and consider quality control measures required to improve data quality. The quality assurance procedures put in place to guarantee effective quality control are then reviewed. An efficient way of implementing quality assurance is to use a quality management system. Different quality management standards are examined along with how quality management systems are implemented. Finally, the benefits of external accreditation are reviewed.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand how the quality of an analytical result may be expressed

2 Understand features of quality control and quality assurance

3 Understand quality management systems

4 Understand the accreditation process.

# Unit content

1 **Understand how the quality of an analytical result may be expressed**

*Features of quality*: quality as closeness to the true value; accuracy; precision; repeatability; reproducibility

*Different types of error*: random; bias; reasons for error eg incompetence, calculation, transcription, unsuitable method used, contamination, extraction/sample preparation technique, interferences, calibration errors, sampling errors, losses and degradation; consequences of the reason for error

*Minimising types of error*: elimination of bias; minimisation of spread of random errors; ways of reducing error eg training, performing calculations on computer, system of double checking entry of data, method validation, steps to reduce contamination, optimising extraction/sample preparation, select method or modifying method to reduce interference, rigorous calibration procedures, validated sampling procedure, adequate sample storage

*Distribution of results*: mean result; distribution of results about mean; normal distribution curve; standard deviation from the mean; % results between $\pm 2\sigma$ and $\pm 3\sigma$

2 **Understand features of quality control and quality assurance**

*Internal quality control measures*: use of suitable quality materials; analysing blanks; analysing samples of known concentration/spiked samples; method validation; sampling method; sampling plan

*External quality control measures*: inter-laboratory comparisons; proficiency testing eg aquacheck, CONTEST, EQA, FAPAS, LEAO, MAPS, QMS, QWAS, RICE, WASP; benefits; organisation; quantification of performance eg z score, $E_n$ number, Q score, organisms isolated and identified (microbiology)

*Features of quality assurance*: activities providing confidence that results are correct eg staff training, record keeping, data management, provision of adequate laboratory, appropriate storage for samples and materials, sample entry procedures, traceability, calibration, maintenance, ensuring validated methods are used; carrying out documented statistical analysis on data

*Control charts*: calculation of standard deviation; setting confidence limits; Sewhart Chart; Moving Average Chart; CUSUM chart; confidence limits; actions when results are outside confidence limits

3 **Understand quality management systems**

*Features of a quality management system*: management structure; chain of responsibility; third party assessment; documentation; records eg calibration, validation, quality control; training; auditing; review; quality cycle

*Quality management standards*: ISO 9001; ISO/IEC 10725; ISO 15189; GLP; applicability to different types of laboratory

*Operation of a quality management system*: description specific to real workplace; quality manual; quality procedures; standard operation procedures; work instructions; locally held documents; records; controlled copies; audit eg internal, external; views eg management view of operation of processes, views of other staff of operation of processes, customer views; analysis eg analysis of data, records, audit report on reconciliation of processes, data and records

*Differences between quality management systems*: laboratories with different functions eg water analysis, food analysis, control of a manufacturing process, contract oil analysis, forensic, microbiological; laboratories of different sizes; allocation of roles of staff

4 **Understand the accreditation process**

*Benefits of accreditation*: benefits to business eg economic benefits, reputation and competitiveness, customer/laboratory relationships, reliability reduces risks; benefits to government eg simplification, common standard across range of laboratories, improved public confidence; benefits to the individual eg confidence in contributing to a service of proven high quality

*Accreditation procedures*: accreditation bodies eg United Kingdom Accreditation Service (UKAS), Clinical Pathology Accreditation (UK) Ltd, GLP Monitoring Authority; accreditation process eg UKAS (accreditation standard, application, pre-assessment visit, initial assessment visit, actions, approval, reassessment)

*Influence of accreditation*: effect on quality management system eg suggestions for improvement implemented ahead of planned time, greater emphasis on record keeping and maintenance of standard procedures; case study on an accredited laboratory

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand how the quality of an analytical result may be expressed | 1.1 discuss features of the quality of analytical results<br>1.2 evaluate different types of error<br>1.3 explain how errors may be minimised<br>1.4 express the distribution of results in statistical terms |
| LO2 Understand features of quality control and quality assurance | 2.1 explain internal quality control measures<br>2.2 review the benefits of external quality control<br>2.3 discuss the features of quality assurance<br>2.4 explain the use of control charts |
| LO3 Understand quality management systems | 3.1 review the features of a quality management system<br>3.2 compare quality management standards<br>3.3 explain the operation of a quality management system<br>3.4 analyse the differences between quality management systems in two laboratories |
| LO4 Understand the accreditation process | 4.1 explain the benefits of accreditation<br>4.2 discuss laboratory accreditation procedures<br>4.3 analyse how accreditation may influence the quality management system |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

*Unit 4: Chemical Laboratory Techniques*

*Unit 6: Analysis of Scientific Data and Information*

*Unit 7: Laboratory Management*

*Unit 12: Analytical Chemistry*

*Unit 22: Management of Projects*

*Unit 23: Managing the Work of Individuals and Teams*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

### Delivery

Learners who work in analysis will find many of the concepts covered in the unit straightforward and will be able to work on assignments with little direction. Learners who are not employed in an analytical laboratory will need to visit laboratories and discuss how they operate to maintain the high quality of their data. Repetitive analysis and simulation may support learner understanding. Although the emphasis is on analytical chemistry results, most of the features of quality management systems also apply to other types of analysis, for example microbiology. Technicians who do not carry out this type of analysis may still appreciate features such as statistical treatment of numerical results.

For learning outcome 1, learners must have experience of carrying out routine analysis. Where distribution of results is concerned, learners could be given data to analyse.

Visits to analytical laboratories will help learners who do not work in the industry to identify the features of quality control and quality assurance. Many UKAS accredited laboratories routinely use control charts.

The UKAS website provides useful information about the benefits of accreditation and the accreditation process. This can be supplemented by visiting speakers from a laboratory which has gone through the accreditation process.

### Assessment

For learning outcome 1, learners must have a specific context in which to set their analysis, for example their workplace or the centre environment. Learners must complete tasks covering features of quality, different types of error and how errors may be minimised. Learners could be given data to analyse. Learners can then discuss how data follow a normal distribution curve or are skewed in some way. Ideally, the context used for learning outcome 1 will be used for the other learning outcomes.

For learning outcome 2, learners could produce a suitable document containing their reflections on the features of quality control and quality assurance apparent in a laboratory they are familiar with. Learners could then explain the actions taken when results fall outside the parameters set on control charts and how control charts are updated on a regular basis.

For learning outcome 3, learners will require case studies or observations from visits, on which to base their work and generate evidence towards meeting the assessment criteria.

For learning outcome 4, learners could carry out a case study. They could design and deliver a presentation explaining the benefits of accreditation, the accreditation process and how a quality management system may be affected by accreditation.

## Resources

Learners require access to a laboratory where routine analysis can be performed.

## Employer engagement and vocational contexts

Learners will benefit more from this unit if they work in an analytical laboratory or can visit a suitable laboratory. Details of the elements of a quality management system, and control of the analytical process, are more easily understood where learners have access to an industrial laboratory.

# Unit 22: Management of Projects

Unit code: J/601/0302

Level: 4

Credit value: 15

## Aim

This unit provides an understanding and experience of project management principles, methodologies, tools and techniques that may be used in industry and the public sector.

## Unit abstract

Management of projects is a key element to ensure successful scientific investigations related to academic research, company research and development or consultancy.

Through this unit learners will develop an understanding of what constitutes a project and the role of a project manager. They will examine the criteria for the success or failure of a project, evaluate project management systems and review the elements involved in project termination and appraisal.

Learners will also understand the need for structured organisation within the project team, effective control and coordination and good leadership qualities in the project manager. They will be able to analyse and plan the activities needed to carry out a project. This includes how to set up a project, how to control and execute a project, how to cost a project and how to carry out project reviews using a specialist project management software package. Together with factors associated with effecting project change, learners will also appreciate how the project fits into the strategy or business plan of an organisation.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the principles of project management

2 Be able to plan a project in terms of organisation and people

3 Be able to manage project processes and procedures.

# Unit content

1 **Understand the principles of project management**

*Project management*: project management and the role of the project manager eg management of change, understanding of project management system elements and their integration, management of multiple projects, project environment and the impact of external influences on projects; identification of the major project phases and why they are required; understanding of the work in each phase; the nature of work in the lifecycles of projects in various industries

*Success/failure criteria*: the need to meet operational, time and cost criteria; define and measure success eg develop the project scope, product breakdown structure (PBS), work breakdown structure (WBS), project execution strategy and the role of the project team; consideration of investment appraisal eg use of discount cash flow (DCF) and net present value (NPV); benefit analysis and viability of projects; determine success/failure criteria; preparation of project definition report; acceptance tests

*Project management systems*: procedures and processes; knowledge of project information support (IS) systems; how to integrate human and material resources to achieve successful projects

*Terminating the project*: audit trails; punch lists; close-out reports

*Post-project appraisals*: comparison of project outcome with business objectives

2 **Be able to plan a project in terms of organisation and people**

*Organisational structure*: functional, project and matrix organisational structures eg consideration of cultural and environmental influences, organisational evolution during the project lifecycle; job descriptions and key roles eg the project sponsor, champion, manager, integrators; other participants eg the project owner, user, supporters, stakeholders

*Roles and responsibilities*: the need for monitoring and control eg preparation of project plans, planning, scheduling and resourcing techniques

*Control and coordination*: use of work breakdown structures eg to develop monitoring and control systems, monitoring performance and progress measurement against established targets and plans; project reporting; change control procedures; the importance of cascading; communications briefing; instilling trust and confidence in others

*Leadership requirements*: stages of team development eg Belbin's team roles, motivation and the need for team building, project leadership styles and attributes; delegation of work and responsibility; techniques for dealing with conflict; negotiation skills; chair meetings

*Human resources and requirements*: calculation; specification; optimisation of human resource requirements; job descriptions

3 **Be able to manage project processes and procedures**

*Project organisation*: the product breakdown structure (PBS) and the work breakdown structure (WBS); project execution strategy and the organisation breakdown structure (OBS) eg preparation of organisational charts, task responsibility matrix, statement of work (SOW) for project tasks

*Project management plans*: the why, what, how, when, where and by whom of project management eg contract terms, document distribution schedules, procurement, establishing the baseline for the project

*Scheduling techniques*: relationship between schedules, OBS and WBS; bar charts; milestone schedules; network techniques; resourcing techniques; computer-based scheduling and resourcing packages; project progress measurement and reporting techniques; staff-hours, earned value and progress ‘S’ curves; critical path analysis and reporting; milestone trending

*Cost control techniques*: cost breakdown structure eg types of project estimate, resource needs, estimating techniques, estimating accuracy, contingency and estimation, bid estimates, whole-life cost estimates, sources of information, cost information sensitivity, computer-based estimating; allocation of budgets to packages of work; committed costs; actual costs; cash flow; contingency management

*Performance*: cost performance analysis eg budgeted cost for work scheduled (BCWS) budgeted cost for work performed (BCWP); concept of earned value; actual cost of work performed (ACWP); cost performance indicators

*Change control procedures*: the need for formal control of changes eg project impact of changes, principles of change control and configuration management; changes to scope, specification, cost or schedule; change reviews and authorisation; the formation of project teams; project initiation and start-up procedures

*Recommendations*: changes in relation to eg scope, specification, cost, improving reliability of outcomes

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the principles of project management | 1.1 explain the principles of project management<br>1.2 discuss viability of projects with particular emphasis on the criteria for success/failure<br>1.3 explore principles behind project management systems and procedures<br>1.4 explain key elements involved in terminating projects and conducting post-project appraisals |
| LO2 Be able to plan a project in terms of organisation and people | 2.1 plan the most appropriate organisational structure<br>2.2 discuss roles and responsibilities of participants within a project<br>2.3 carry out the control and co-ordination of a project<br>2.4 document project leadership requirements and qualities<br>2.5 plan specific human resources and requirements for a project |
| LO3 Be able to manage project processes and procedures | 3.1 design the project organisation with reference to prepared project management plans<br>3.2 use project scheduling and cost control techniques<br>3.3 report the methods used to measure project performance<br>3.4 report project change control procedures<br>3.5 discuss the outcomes of the project and make recommendations |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 5: Project for Applied Science*
- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 7: Laboratory Management*
- *Unit 8: Work-based Investigation*
- *Unit 21: Quality Assurance and Quality Control*
- *Unit 23: Managing the Work of Individuals and Teams*.

## Essential requirements

## Delivery

This unit gives learners the opportunity to build on the concepts learned in *Unit 7: Laboratory Management*, by managing a 'live' project. Therefore a practical approach to delivery must be adopted.

For learning outcome 1, learners must choose their own project and outline their plan of action in writing. Tutors need to check their plans to ensure that the project is realistic and achievable before learners proceed. During the course of carrying out their project, learners should be allowed to make mistakes and learn from them. However, tutors may need to provide some guidance which should be recorded so that it can be taken into account when grading the unit.

It is important that learners do not spend too much time carrying out numerical work, or preparing or analysing large quantities of data. The analysis of data is an inevitable aspect of project management. It is best learned using pre-prepared examples in electronic form that enable the principles to be demonstrated quickly without oversimplifying the complexity of everyday project operations.

For the operation of complex proprietary computer software systems, project managers must know what to expect from these facilities, but are not necessarily expected to be able to operate them.

Project management principles and techniques are important, together with an appreciation of how the various operations within the project integrate with each other.

Learners must be given the opportunity to chair meetings.

## Assessment

Although this unit may be linked with *Unit 5: Project for Applied Science*, the emphasis must be on the management of the project rather than the project itself. Where projects are carried out by small groups, the project manager must keep detailed records of each individual's performance in order to confirm achievement of the assessment criteria and to allow achievement to be audited.

For learning outcome 1, learners must demonstrate an understanding of the principles of project management and discuss the criteria for success or failure. This must also include recognition of the importance of selecting appropriate systems for the successful management and completion of the project.

Evidence for learning outcome 2 must include a plan where learners identify the most appropriate organisational structure for the project, highlighting the roles and responsibilities of those involved, including the project manager. In addition, there must be an account of how the project is controlled and coordinated.

A large part of the evidence for learning outcome 3 could be linked with that for learning outcome 2, ie design of the project organisation and scheduling. Reporting of the methods used to measure project performance and project control procedures could be incorporated into an overall evaluation of the exercise.

## Resources

Appropriate software packages need to be used to demonstrate project control and reporting techniques which might include time and cost scheduling packages, documentation and procurement control packages, spreadsheet packages and graphic presentation packages.

Other packages, for items such as risk analysis, project accounting and procurement control, could be used to illustrate particular techniques in specific industries.

Access to real project data in electronic spreadsheet form would be an advantage.

## Employer engagement and vocational contexts

Learners would benefit from visits to organisations engaged in project work as a part of academic research, research for public bodies, company research and development or consultancy activities.

An ideal situation would be for learners to manage a project of interest to a particular organisation.


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# Unit 23: Managing the Work of Individuals and Teams

Unit code: R/601/0304

Level: 5

Credit value: 15

## Aim

This unit develops learners' understanding and skills associated with managing the work of individuals and teams. It enhances the ability to motivate individuals and to maximise the contribution of teams to achieve outcomes.

## Unit abstract

All scientific tasks are carried out by personnel working either as an individual or as a member of a team. The role of an individual can be defined by a job description that states responsibilities, objectives and performance targets.

At one or more stages during the execution of a task it is common to assess performance through an appraisal system designed to evaluate progress, motivate future performance and set new targets. A similar procedure would apply to teamwork and team performance.

In this unit learners will develop the skills associated with setting job descriptions and targets for individuals and teams and then review their performance.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to establish the objectives of individuals

2 Be able to evaluate the performance of individuals

3 Be able to establish the roles and responsibilities of teams

4 Be able to review the performance of teams.

# Unit content

1 **Be able to establish the objectives of individuals**

*Job description*: analysis of jobs; behaviour; responsibilities and tasks; pay; bonus; incentives

*Employee*: any person working in the applied science sector with responsibility to a line manager

*Roles*: any specific activity or group of activities within the applied science sector

*Responsibilities*: direct and indirect relationships; relations between personal and team responsibility

*Performance targets*: personal; financial; quantity and quality; incorporation within a job description; setting and monitoring performance targets

2 **Be able to evaluate the performance of individuals**

*Employee appraisal system*: reasons for using performance appraisals eg to determine salary levels and bonus payments, promotion, establish strengths and areas for improvement, training needs, communication; establishing appraisal criteria eg production data, personnel data, judgemental data; rating methods eg ranking, paired comparison, checklist, management by objectives

*Staff appraisal schedule*: conduct of performance reviews eg by supervisor, peers, committee, subordinates or self-appraisal

*Feedback of results*: comments on positive and negative aspects of performance related to targets, conduct and timekeeping; resolution of conflicts

*Encouragement*: as a motivator for the achievement of performance targets eg strengths, rewards

3 **Be able to establish the roles and responsibilities of teams**

*Teams*: management teams and peer groups eg focus groups, task groups, project groups, panels; purpose of teams eg long and short term, specific project or task, seeking views within the company and from external sources, communication

*Team responsibilities*: to superiors; subordinates; the business; each other and external groups eg meeting performance targets, communicating results, confidentiality, deadlines

*Targets*: realistic deadlines; new and or amended outcomes

*Internal team management*: hierarchical; functional

4 **Be able to review the performance of teams**

*Team performance*: appraisal systems; reasons for appraising team performance eg team effectiveness, contribution to business, constitution of team, identifying individual contributions to the team effort and determining the need to establish other team criteria

*Performance criteria*: formulate appropriate criteria eg outcome data, achieved improvements, employee morale, value added

*Performance review*: conduct a team performance review eg as individual manager, outside person; team self-appraisal; feedback of results and resolution of conflicts within the team

*Team motivation*: encouragement of overall team performance as a motivator for the achievement of objectives

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to establish the objectives of individuals | 1.1 identify the essential elements of a job description<br>1.2 design a job description for an employee<br>1.3 produce a schedule of the roles and responsibilities of individuals<br>1.4 agree performance targets for an individual |
| LO2 Be able to evaluate the performance of individuals | 2.1 explore the key factors in establishing an employee appraisal system<br>2.2 develop a staff appraisal schedule for use by a manager<br>2.3 provide feedback to an individual who has undergone an appraisal<br>2.4 encourage an individual to achieve performance targets |
| LO3 Be able to establish the roles and responsibilities of teams | 3.1 identify teams suitable for a variety of purposes<br>3.2 determine the responsibilities of teams to different personnel within an organisation<br>3.3 set suitable targets for teams<br>3.4 compare various types of internal team management |
| LO4 Be able to review the performance of teams | 4.1 identify the reasons for appraising team performance<br>4.2 formulate the criteria by which the performance of different types of teams can be measured<br>4.3 conduct a performance review of a team<br>4.4 produce a report on the factors that are likely to motivate a team to achieve its defined objectives |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 7: Laboratory Management*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

## Delivery

Learners are generally expected to work individually. However, certain criteria may lend themselves to teamwork and, where this occurs, tutors should ensure that they keep sufficiently detailed records to enable an External Examiner to audit assessment. Learners must provide sufficient evidence to meet the assessment criteria on an individual basis.

## Assessment

It is essential that learners have some experience of supervisory or management roles to benefit fully from the unit. Ideally, learners should be employed or have experience in an occupation which relates to the unit. Alternatively, suitable work-based experience is appropriate.

## Resources

Learners must have access to a range of textbooks relating to human resources management in applied science-based settings. Suitable guest speakers should be invited to provide an overview of relevant aspects of the unit, which might include applications of personnel/human resource management, motivation, organisational structures, management and appraisal techniques.

## Employer engagement and vocational contexts

Wherever possible, learners must base their examples on specific tasks and teamwork within local applied science-related industries. They should study the structure and activities of the company and, where possible, visit the company to witness practices and procedures relating to individual and group work, target setting and evaluation.

# Unit 24: Nuclear Chemistry

Unit code: D/601/0418

Level: 5

Credit value: 15

## Aim

This unit provides learners with an understanding of stability and radioactive decay in isotopes. Applications of radioactive isotopes in chemistry and medicine, nuclear power and the impact of radioactivity on society and the environment are also explored.

## Unit abstract

This unit is designed to provide comprehensive coverage of nuclear chemistry with many of the principles building on those gained in level 4 core units. The unit covers four broad areas with the intention of appealing to learners who wish to work in a nuclear-related industry or those who already work in the sector and wish to further develop their understanding of aspects of nuclear chemistry.

The unit commences with a study of aspects of nuclear structure and the criteria for nuclear stability. The use of a range of isotopes in spectroscopy, analysis and investigation of chemical reaction pathways is explored together with applications of radiotracers in medicine.

Aspects of nuclear power production relating to nuclear fuels, types of nuclear reactor and their operation and control are considered. Mining and enrichment of uranium ore, reprocessing used fuel and classification and management of waste are reviewed.

The unit concludes by considering the dangers of radiation exposure, nuclear power accidents and public perception of the use of nuclear power.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the behaviour of the nucleus

2 Understand the use of isotopes in chemistry and medicine

3 Understand the chemistry of the nuclear power industry

4 Be able to report on the impact of radioactivity on society and the environment.

# Unit content

1 **Understand the behaviour of the nucleus**

*Nuclear structure*: nuclear size compared to radii of atom; proton and neutron properties, mass, charge; nuclear size, relationship of number of nucleons to the cube of the radius; density of nuclear matter; forces between nucleons including calculations of electrostatic and gravitational forces; graphical representations of attraction/repulsion against distance between centres; mass defect and binding energy including calculation of nuclear binding energy and average binding energy per nucleon

*Nuclear stability and radioactive decay*: nuclear stability in terms of number of neutrons to protons; interpretation of proton numbers vs neutron number plots

*Spontaneous radioactive decay*: calculations associated with the kinetics of decay; half-life; nuclear equations; decay series

*Properties of alpha, beta and gamma radiation*: penetrating power and behaviour in an electric field

*Health and safety regulations*: awareness of important regulations eg Ionising Radiations Regulations (1999), Radioactive Substances Act (1993), The Ionising Radiation (Medical Exposure) Regulations (2000)

2 **Understand the use of isotopes in chemistry and medicine**

*Use of isotopes in spectroscopy*: infrared spectroscopy, application of deuterium exchange reactions; multinuclear nuclear magnetic resonance spectroscopy eg $^{31}P$ nmr, $^{11}B$ nmr, $^{19}F$ nmr; nuclear spin quantum number; spin relaxation time; quadrupole moment; chemical shift ranges; spin-spin coupling; Mössbauer spectroscopy limited to basic principles and applications to inorganic chemistry

*Use of isotopes in chemistry and analysis*: kinetic isotope effects; application to mechanistic studies of chemical reactions; radiocarbon dating including calculations; use of radioisotopes in analytical applications eg solubilities of sparingly soluble salts, vapour pressures of involatile substances

*Use of isotopes in medicine*: radiotracers eg $^{131}I$ in thyroid gland analysis; cobalt as a source of gamma radiation for cancer treatment; technetium-99 in diagnostic radiopharmaceuticals; biochemical analysis eg radioimmunoassays; recent advances in radioisotope use; positron emission tomography (PET) with 18F tracer

3 **Understand the chemistry of the nuclear power industry**

*Nuclear fuels*: fissile nuclei; uranium-233; uranium-235; plutonium-239; use of moderators (water/graphite); nuclear fission; chain reactions; uranium-238 as non-fissile but fertile in formation of fissile plutonium-239; nuclear fuels including enriched $UO_2$, natural $UO_2$, natural uranium/enriched $UO_2$, $PuO_2$ and $UO_2$

*Nuclear power stations*: diagrammatic structure of typical reactors found around the world (pressurised water reactors (PWR), boiling water reactor (BWR), pressurised heavy water reactor (CANDU), gas-cooled reactor (Magnox and AGR), light water graphite reactor and fast neutron reactor (FBR)); function mechanisms of different reactor types (fuel, moderator, control rods, coolant, pressure vessel, steam generator, containment)

*Nuclear fuel cycle*: mining and milling of uranium ore; enrichment including formation of uranium hexafluoride from uranium oxide; diffusion process; centrifuge enrichment; fuel element fabrication; nuclear wastes; classification and management of waste

*Reprocessing used fuel*: magnox and thermal oxide reprocessing from AGR/light water reactors; use of nitric acid; chemical separation; formation of mox; formation of uranium fuel pellets; vitrification of wastes

4 **Be able to report on the impact of radioactivity on society and the environment**

*Radiation units*: rem; millirem; rads; curie; becquerel; gray; sievet

*Radiation exposure*: background radiation; radiation dosage; environmental radiation exposure; acute radiation exposure; biological effects of radiation eg radiation sickness; European dosage limits

*Nuclear power accidents*: causes and consequences of nuclear accidents; examples and case studies of nuclear power station accidents eg Chernobyl, Three Mile Island, Windscale UK, Chalk River Island, Canada; environmental monitoring

*Nuclear power and society*: public perceptions and media reporting; nuclear power station safety; nuclear power as a future energy source; potential of nuclear fusion

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the behaviour of the nucleus | 1.1 explain nuclear structure using specified calculations<br>1.2 discuss factors affecting nuclear stability<br>1.3 explain radioactive decay using specified equations<br>1.4 discuss the properties of alpha, beta and gamma radiation<br>1.5 review health and safety regulations governing working with radioactive materials |
| LO2 Understand the use of isotopes in chemistry and medicine | 2.1 explain the application of isotopes in spectroscopy<br>2.2 explain the application of isotopes in chemical reactions and analysis<br>2.3 discuss the applications of radioisotopes to medicine |
| LO3 Understand the chemistry of the nuclear power industry | 3.1 explain how nuclear fuels function<br>3.2 explain the function of different types of nuclear power station<br>3.3 explain the nuclear fuel cycle<br>3.4 discuss methods used in the reprocessing of spent fuels |
| LO4 Be able to report on the impact of radioactivity on society and the environment | 4.1 define the units used in measuring radiation<br>4.2 report on biological effects of radiation exposure<br>4.3 draw conclusions from investigations into nuclear power station accidents<br>4.4 review public perceptions of nuclear power |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 3: Physical Chemistry*
- *Unit 12: Analytical Chemistry*
- *Unit 14: Industrial Chemistry*
- *Unit 17: Medicinal Chemistry*.

## Essential requirements

## Delivery

Where appropriate, the unit content must be exemplified by case studies, problems and practical exercises. For some topics the delivery of material can be emphasised by viewing relevant DVD programmes or online research. Illustrative material must be selected to emphasise the relevance of the learning outcomes to everyday life or industrial application.

## Assessment

For learning outcome 1, assessment must confirm learners' understanding of the behaviour of the nucleus in terms of factors that affect nuclear stability and determine radioactive decay. An appreciation of the characteristic properties of alpha, beta and gamma radiation must be clearly demonstrated.

Learning outcome 2 must assess the use of isotopes in chemistry and medicine. Examples should be selected that demonstrate learners' abilities to explain the application of isotopes in studying reaction mechanisms as well as their use as a tool in analytical chemistry. Spectroscopic applications including multinuclear magnetic resonance spectroscopy should also be assessed in terms of analytical applications. Learners must demonstrate an ability to research and discuss specific examples of the usefulness of radioisotopes in diagnostic medicine.

For learning outcome 3, assessment must confirm learners' understanding of the facets of nuclear power with particular emphasis on nuclear fuels, power generation in a variety of nuclear reactors and the enrichment and reprocessing of nuclear fuel.

For learning outcome 4, assessment must confirm learners' abilities to review the impact of radioactive materials and processes, on society and the environment.

## Resources

Learners will need access to library and information technology resources, tutorial and technical support.

## Employer engagement and vocational contexts

Visits to local industry, for example nuclear power stations, hospital medical physics departments, universities operating nuclear magnetic resonance equipment or radioisotope environmental monitoring units will enhance the delivery of this unit.


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# Unit 25: Nanotechnology

Unit code: K/601/0311

Level: 4

Credit value: 15

## Aim

This unit examines the role of nanotechnology at the interface of Chemistry, Biology, Physics and Engineering, especially its use in achieving effects not possible in individual atoms or bulk materials.

## Unit abstract

This unit provides learners with an introduction to the fundamental principles and commercial use of nanotechnology and embraces the interdisciplinary nature of the subject. Scientific theory relevant to the nanoscale is covered. Learners will also cover key concepts in engineering, physics, chemistry and biology and their application in solving nanotechnology problems.

Learners will develop practical skills and techniques to evaluate current nanotechnology fabrication methods. Current, and potential future, applications in energy, medicinal engineering, physics, chemistry, biology, electronics and computing are covered.

Learners will gain an appreciation of the commercial applications of nanotechnology and the challenges for the future.

## Learning outcomes

On successful completion of this unit a learner will:

1 Know how structure controls properties at the nanoscale dimension

2 Understand key concepts in engineering, physics, chemistry, and biology used to solve nanotechnology problems

3 Be able to evaluate current nanotechnology fabrication methods

4 Know current and potential future commercial nanotechnology applications.

# Unit content

1 **Know how structure controls properties at the nanoscale dimension**

*'There's plenty of room at the bottom'*: benefits of reducing a problem to the nanoscale; the nanoscale paradigm

*Nanoscience*: definitions; history; current commercial applications; nanoscale science; technology principles

*Control of properties*: Carbon Nanotube Technologies (CNT) eg from diamond to graphite to graphene to buckminster-fullerene to CNT, fabricating and key applications of carbon allotropes

*Lengthscale controls of electronic properties*: quantum devices; quantum dots; quantum wires; quantum wells; quantum computing

2 **Understand key concepts in engineering, physics, chemistry, and biology used to solve nanotechnology problems**

*Surface and colloid chemistry*: principles of surface/colloid chemistry; function of surfaces in nanotechnology devices; colloid chemistry and particles in nanotechnology

*Thin film applications*: thin film deposition and characterisation processes; plasma deposition/surface treatment; applications of thin film technology

*Chemical templating*: soft chemical fabrication; templating molecules; sol-gel synthesis; opals and photonic crystals; 3-DOM materials

*Quality control in nanofabrication*: failure analysis; analysis and measurement techniques in nanoscience; imaging techniques eg SEM, SPM-AFM; surface and bulk materials analysis

3 **Be able to evaluate current nanotechnology fabrication methods**

*Nanofabrication*: routes eg nanolithography, thin film processes, MEMS and semiconductors, physical limits to UV, X-ray and e-beam lithography, self-assembly, bottom-up fabrication and outline of Complex Adaptive Systems

*Polymers and organic molecules*: polymer chemistry applications in nanotechnology; organic molecules and supramolecular chemistry; liquid crystal and flat panel displays

*Technology review*: case study of the commercial application of nanotechnology; the company; how nanotechnology addresses a need, the technology; product and market

4 **Know current and potential future commercial nanotechnology applications**

*Commercial applications*: consumer markets for nanomaterials eg electronics, photonics, optoelectronics, magnetic data storage, MEMS/NEMS, nano-bio applications, computing technologies (present and future), nano-medicine

*Moore's Law*: semiconductors; history and future 1950-2020; material requirements for silicon; quantum effects (desired or not); nanofabrication techniques in semiconductors

*Nanotechnology challenges*: challenges eg skilled workforce, public and private investment, enhanced material risks of nanoparticles, public perception

*Career prospects*: nanotechnology career prospects eg materials science and processing, nano-bio applications, bioinformatics, nanomagnetics, quantum computing, IT

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Know how structure controls properties at the nanoscale dimension | 1.1 describe the benefits of reducing a problem to the nanoscale<br>1.2 outline the definitions, history and current commercial applications of nanoscience<br>1.3 describe the control of properties by structure in the carbon allotropes<br>1.4 define the lengthscale controls of electronic properties |
| LO2 Understand key concepts in engineering, physics, chemistry, and biology used to solve nanotechnology problems | 2.1 explain the principles of surface/colloid chemistry<br>2.2 discuss thin film deposition and characterisation processes<br>2.3 explain chemical templating<br>2.4 compare imaging techniques for quality control in nanofabrication |
| LO3 Be able to evaluate current nanotechnology fabrication methods | 3.1 carry out an assessment of different nanofabrication routes to an assigned device design<br>3.2 plan commercial nanofabrication routes for the assigned device<br>3.3 produce a report assessing cost, quality and safety of the planned route<br>3.4 present the findings and make recommendations |
| LO4 Know current and potential future commercial nanotechnology applications | 4.1 describe commercial applications of nanomaterials<br>4.2 state Moore's Law and materials requirements for its continuation in silicon to 2020<br>4.3 outline current challenges to nanotechnology<br>4.4 describe future growth areas in nanotechnology including career prospects |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 2: Organic Chemistry*
- *Unit 16: Polymer Chemistry*.

## Essential requirements

## Delivery

It is assumed that nanotechnology experimentation is not possible in the learning environment. However, any nanoscience that facilities and/or health and safety permit will be hugely beneficial, for example colours of solutions of CdSe nanoparticles of different sizes. Visits to a nanofabrication facility would also add interest and context to the unit content.

Delivery of learning outcome 1 must focus on how property and function are controlled by dimensionality and lengthscale. A historical context starting with Feynman's famous 'there's plenty of room at the bottom' lecture would be of great benefit.

For learning outcome 2, appreciation of complex three-dimensional structures should be reinforced by the use of computer 3D imagery where possible.

Learning outcome 3 requires a project-based review of a commercial application of nanotechnology. This must be a product or technology that is being prepared for market, but it does not have to be on the market yet. Learners must review the technology, the product and how nanotechnology meets a specific need. The report must focus on four key areas; the company, the nanofabrication technology, the nano-aspects of the product and the market.

For learning outcome 4, emphasis must be placed on the safety implications of working with nanosized particles. Appropriate software and ICT facilities should be used to encourage independent learning.

## Assessment

For learning outcome 1, learners must demonstrate knowledge of the role structure and dimensionality play in determining the physical properties of nanostructures, and outline the history and current state of nanotechnology.

For learning outcome 2, learners must explain the underlying chemical and physical concepts in surface/colloid science, chemical templating and thin film deposition. They must assess the use of the various imaging techniques for quality control and the characterisation of typical structures each technique produces.

For learning outcome 3, learners could work individually or in small groups to produce a report and presentation. If group work is selected, each learner must provide sufficient evidence to meet the assessment criteria on an individual basis. The relative merits of various possible fabrication strategies should be evaluated. One of these strategies must be selected on the basis of this evaluation and then related commercial and safety implications assessed.

For learning outcome 4, learners must demonstrate knowledge of the current challenges and potential future directions of nanotechnology, and the materials implications for the continuation of Moore’s Law over the next 10 years.

## Resources

Learners need access to library and ICT resources to support unit delivery.

## Employer engagement and vocational contexts

Learners will benefit from visits to laboratories engaged in investigations or research into nanotechnological processes, for example in chip or hard-disk fabrication, agri-food research or nano-medicine. This would enable learners to observe the application of nanofabrication techniques within a particular context.

# Unit 26: Materials Science and Technology

Unit code: H/601/0419

Level: 4

Credit value: 15

## Aim

This unit examines aspects of materials science. Learners are provided with an understanding of structure-property relationships, analytical testing and evaluation and the selection of a material for a given application.

## Unit abstract

Materials science is perhaps one of the oldest scientific fields, with some of the earliest examples of ceramic and metal experimentation pre-dating recorded history. These areas were joined by polymers in the early 20th century, and the discipline now displays considerable growth in areas such as smart materials. This unit develops knowledge and understanding gained in the core units on the structure of solids enabling learners to gain an understanding of the principles of materials science.

The unit begins with an examination of the causes behind a material's behaviour and properties by considering the microscopic nature of matter. This leads into an exploration of the processes involved in altering these properties on a permanent or transitory basis, the latter being most significant with smart materials.

To enable learners to understand how a material is characterised by its properties, the unit covers the techniques commonly used to analyse matter, such as electron microscopy and neutron diffraction, as well as the industry standard physical tests. The unit concludes with an overview of the processes used in selecting materials for given applications, involving a look at the compromises that need to be taken.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the structure-property relationships for materials

2 Understand the factors that control the properties of materials

3 Be able to characterise a material from the outcomes of analytical tests

4 Understand the selection process for choosing a material in a given application.

# Unit content

1 **Understand the structure-property relationships for materials**

*Microscopic structure*: bonding between atoms; packing of atoms in solids; polymer chains; cross linking; fundamentals of elasticity; plastic flow; role of defects eg dislocations; micro-mechanisms of fracture; creep mechanisms; corrosion of materials; wear; polymer degradation

*Physical properties*: density; thermal expansion; specific heat capacity; heat transfer coefficient; electrical insulating properties; magnetic properties; nuclear properties eg cross section, isotopic composition; phase change temperatures

*Mechanical properties*: elastic properties; strength; hardness; ductility; toughness; fatigue resistance; creep resistance; high temperature properties; corrosion resistance; wear resistance; fracture toughness

2 **Understand the factors that control the properties of materials**

*Composition*: alloying; co-polymerisation; additives; cross-linking; crystallinity; composite materials

*Material processing*: phase equilibrium diagrams; solid solution hardening; work hardening; phase transformations eg diffusion, non-diffusion transformations; kinetics of transformations eg nucleation, growth; radiation hardening

*Smart materials*: external stimuli; non-Newtonian fluids; ferrofluids; complex fluids; shape memory materials; magnetoresponsivity; thermoresponsivity; electrochromic materials; photochromic materials; piezoelectricity; applications of smart materials eg LCD screens, 4WD systems; replacement of traditional materials with smart materials; economic and environmental costs of smart materials

3 **Be able to characterise a material from the outcomes of analytical tests**

*Microscopic techniques*: sample preparation eg metallographic, petrographic; optical macroscopy; optical microscopy; electron optical techniques eg Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), Scanning Transmission Electron Microscope (STEM); electron diffraction techniques; x-ray diffraction analysis eg Energy Dispense X-ray Analysis (EDXA), Wavelength Dispersive X-ray Analysis (WDXA); neutron diffraction; atomic force microscopy; nuclear magnetic resonance imaging (MRI)

*Physical testing*: tensile testing; hardness testing; creep testing; fatigue testing; fracture toughness testing; corrosion testing; international testing standards; quality assurance issues

4 **Understand the selection process for choosing a material in a given application**

*Design requirements*: service requirements; key design properties; normal external conditions; transient conditions; design life; quality; chemical compatibility; reliability eg chances of failure, consequences of failure; cost limitations; aesthetics; maintenance requirements

*Fabrication*: raw material form; availability; joinability; adhesives; castability; forgeability; weldability; coatings; ease of repair

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the structure-property relationships for materials | 1.1 explain the microscopic structure and behaviour of common materials<br>1.2 review the physical properties of materials<br>1.3 justify the use of a material in a given application on the basis of its mechanical properties |
| LO2 Understand the factors that control the properties of materials | 2.1 explain the role of composition on the properties of a material<br>2.2 assess the use of material processing in modifying the properties of a material<br>2.3 evaluate the growth in use of smart materials in traditional material roles |
| LO3 Be able to characterise a material from the outcomes of analytical tests | 3.1 use analytical microscopic techniques in material science<br>3.2 perform physical testing of a given material to characterise its properties, using safe practices |
| LO4 Understand the selection process for choosing a material in a given application | 4.1 evaluate the choice of material in a given application on the basis of the design requirements of the application<br>4.2 justify the choice of a given material in an application on the basis of the material's fabrication |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 1: Inorganic Chemistry*
- *Unit 2: Organic Chemistry*
- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 9: Inorganic Chemistry of Crystal Structures and Transition Metal Complexes*
- *Unit 14: Industrial Chemistry*
- *Unit 16: Polymer Chemistry*.

## Essential requirements

## Delivery

Where possible, the unit must be delivered using a combination of theory and practical experiments. Access to electron microscopes, NMR machines etc could be achieved through arranged visits to analytical, research or medical facilities. The content is sufficiently flexible that this can be biased towards the specialist knowledge of the member of staff concerned as long as the basic understanding of the links are made between the chemistry and the materials science.

## Assessment

Learning outcome 1 involves understanding the links between the properties of a material and its microscopic structure.

Learning outcome 2 considers the mechanisms used to alter the properties of a material. Evidence should include case studies or experimental studies, where appropriate.

Learning outcome 3 examines the role of analytical and physical testing in categorising a material's properties. Evidence must include experimental studies of physical testing.

Learning outcome 4 involves the process for selecting an appropriate material in a given application. Evidence should include case studies where appropriate.

## Resources

Learners will need access to basic metallurgical/materials laboratory preparation and engineering workshop facilities for observations, demonstrations and practical work. This should ideally include apparatus to determine the toughness and hardness of a material. Atomic and nuclear physics equipment, such as gamma ray sources or Tel-X-Ometers, could be used to supplement the analytical testing. Samples of materials, particularly smart materials, should be readily accessible.

## Employer engagement and vocational contexts

Learners will benefit from visits to industrial and research facilities to observe practical applications of materials science and technology.


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# Unit 27: Statistics for Experimental Design

Unit code: J/601/0297

Level: 5

Credit value: 15

## Aim

This unit provides learners with an understanding of the role of statistics in experimental design and hypothesis testing. Learners will be able to use significance testing to make statistical decisions and analyse the relationship between variables.

## Unit abstract

The designing of scientific experiments involves multiple stages, often requiring an understanding of statistical analysis.

The unit starts with an overview of experimental design and examines the basic principles of sampling populations, probability and distributions. Learners will examine and address how statistical decisions form an important part of experimental design. Learners will gain an understanding of hypothesis testing, before looking at the differences between parametric and non-parametric models of analysis.

Understanding statistical decisions is extended to cover the role of significance testing, examining one, two and multiple sample tests. The unit concludes with correlation and linear regression; the mathematical processes are covered, as well as the impact of the limitations of correlation analysis on experimental design.

Emphasis throughout the unit is on a practical approach to applications familiar to learners together with an explanation of the theory underpinning the methods used.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand the role of statistics in experimental design

2 Understand how statistical decisions are made using hypothesis testing

3 Be able to make statistical decisions using significance testing

4 Be able to analyse the relationship between variables.

# Unit content

## 1 Understand the role of statistics in experimental design

*Experimental design*: treatments; controls and replicates; factorial designs; specialised designs eg clinical trials, ecological field studies, microbial assays

*Population sampling*: populations; sampling; sampling error; random sampling; random allocation; use of random number tables

*Probability*: concept of probability; laws of probability eg addition, multiplication; binomial approximation; Poisson approximation

*Probability distributions*: normal probability distribution; standard normal variate; central limit theorem; standard error; confidence limits; student's t distributions

## 2 Understand how statistical decisions are made using hypothesis testing

*Hypothesis testing*: the null hypothesis; significance (alpha) level; type 1 errors; type 2 errors; one tailed tests; two tailed tests; the power of a test; estimation of sample size

*Parametric and non-parametric methods*: assumptions of parametric analysis; the normal plot; transformation; non-parametric methods; selecting the correct test

## 3 Be able to make statistical decisions using significance testing

*One and two sample tests*: one sample z test; one sample t test; sign test; two unpaired sample tests; Wilcoxon ranked-sum test; two paired sample tests; Wilcoxon signed-rank test

*Multiple sample tests*: errors in multiple hypothesis testing; one-way analysis of variance (ANOVA); testing pairs of means; two-way ANOVA; interaction; factorial experimental design; randomised block; latin square; non-parametric; Kruskal-Wallis test

*Categorical data*: $\chi^2$ goodness of fit test; $\chi^2$ test for association; correction for continuity

## 4 Be able to analyse the relationship between variables

*Linear correlation*: scatter diagrams; Pearson's correlation coefficient; Spearman rank correlation coefficient; predicting values; assumptions of linear correlation; transformation; testing the significance of coefficients

*Linear regression analysis*: least squares method; regression equation; assumptions of linear regression; assessing the significance of slope coefficient and intercept; assessing the goodness of fit

*Assessment of agreement*: reproducibility and repeatability; numerical variables; limitations of correlation analysis; use of paired t tests; limits of agreement; analysis of differences; category variables; Cohen's kappa

 

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand the role of statistics in experimental design | 1.1 discuss the factors behind experimental design from a statistical view point<br>1.2 explain the mechanics of population sampling with regards to controlling error<br>1.3 evaluate probabilities using approximation methods |
| LO2 Understand how statistical decisions are made using hypothesis testing | 2.1 assess the use of hypothesis testing in experimental design<br>2.2 illustrate the differences between parametric and non-parametric models of analysis |
| LO3 Be able to make statistical decisions using significance testing | 3.1 carry out one and two sample tests on a given population sample<br>3.2 use multiple sample tests in experimental design<br>3.3 use categorical data to test hypotheses |
| LO4 Be able to analyse the relationship between variables | 4.1 use scatter diagrams to assess linearity with regression lines<br>4.2 carry out linear regression analysis with all assumptions clearly indicated<br>4.3 discuss how the assessment of agreement is utilised in experimental design |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 6: Analysis of Scientific Data and Information*
- *Unit 12: Analytical Chemistry*
- *Unit 13: Environmental Chemical Analysis*.

## Essential requirements

## Delivery

The focus of delivery must be on a practical approach to the application of statistical analysis, although some theoretical background should be included to aid understanding, in particular of probability and parametric methods. There must be a balance between hand calculation (scientific calculator) and software use. Simple examples illustrating the method must be used to build up understanding and confidence before learners use software.

Learners must use the results of analyses as a basis for suggesting improvement in experimental design or extensions of the study in question. They must also be aware of potential errors, for example resulting from data entry, the wrong choice of analysis, misinterpretation and the limitations of the methods used.

## Assessment

Learning outcome 1 involves demonstrating an understanding of how statistics are used in designing experiments. Some emphasis must be placed on understanding the role that sampling, probability and probability distributions have in design, rather than on mathematics. Evidence may be drawn from activities that form a normal part of the applied science programme of study. Learning outcome 2 involves understanding the use of hypothesis testing to make statistical decisions in experimental design. Emphasis must be placed on demonstrating understanding of the application of statistics, rather than the fundamental mathematics.

Learning outcome 3 covers the mathematical techniques used to test significance. Emphasis must be on the accurate application of the methods covered. Learning outcome 4 covers the mathematical techniques used to examine correlation between variables. Emphasis must be on the accurate application of the methods covered, with evidence showing how experiments are designed with correlation limitations in mind.


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## Resources

Learners will need access to IT facilities and appropriate software, to enable them to tackle realistic problems. Many of the operations relevant to applied science programmes can be implemented using a generic spreadsheet package (such as Microsoft Excel). Ideally, this will be supplemented by dedicated mathematical or statistical packages, for example Minitab, SPSS, PASW Statistics or MATLAB.

## Employer engagement and vocational contexts

Learners will benefit from visits to industrial and research facilities to observe practical applications of data analysis, or to gain access to learning materials.

# Unit 28: Work-based Experience

Unit code: D/601/0998

Level: 5

Credit value: 15

## Aim

This unit aims to enable learners to experience the scope and depth of learning which may take place in a work-based context by planning, monitoring and evaluating the work experience.

## Unit abstract

A significant amount of learning can be achieved by carrying out practical activities in a workplace. Learning may be enhanced by taking a more formal approach to work-based activities – by planning, carrying out the activities and reflecting on the benefits of the activities for the business and learner.

This unit is designed to allow flexibility of study for part-time and full-time learners. It is expected that learners will be supervised in the workplace in addition to their academic supervisor.

Learners will have the opportunity, supported by their supervisors, to negotiate and perform activities which will allow them to meet the assessment criteria for this unit. They will recognise the scope of what they have achieved by recording evidence from carrying out the activities. They will also gain maximum benefit by reflecting on and evaluating the work they undertake.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to negotiate industry experience

2 Understand the specific requirements of the placement

3 Be able to undertake work experience as identified

4 Be able to monitor and evaluate own performance and learning.

# Unit content

1 **Be able to negotiate industry experience**

*Suitable organisation and location*: types of establishments for placement eg industry-related work for a client brief at college, existing work environment, different department within current employer's business

*Negotiation*: methods of contacting organisations; methods of undertaking negotiations

*Nature of duties:* type of undertaking eg routine duties and tasks, project work, development of new procedures/protocol

*Supervisors*: roles and responsibilities of academic and industrial mentors

*Expectations of learning*: aims eg proficiency in new tasks and procedures, time management and problem solving skills, reflection, discuss progress with others, teamwork

*Business constraints*: consideration of possible limitations eg need to be fully trained, adherence to quality systems, health and safety considerations, supervision time, workload, customer satisfaction, limited staffing, cost of materials

2 **Understand the specific requirements of the placement**

*Tasks*: details of activities eg specific hourly, daily, weekly routine and non-routine tasks; breakdown of a project into stages; new procedures/protocol

*Prioritise*: reasons for rationalisation of the order of tasks; methods of prioritising work

*Plan for the work experience*: methods used to develop detailed plan with schedule of tasks; proposed dates for reviews; expected input from supervisors

*Benefits to organisation and learner*: advantages to business eg allowing more routine tasks to be carried out, allowing procedures/techniques to be developed, increasing responsiveness, identifying cost saving measures; advantages to learner eg understanding how a business operates, understanding importance of teamwork, learning new techniques, development of problem-solving and time management skills

3 **Be able to undertake work experience as identified**

*Carry out the planned activities*: realisation eg carrying out tasks and project work according to relevant legislation, training and codes of practice; developing new procedures or protocol

*Record activities in the appropriate manner:* systematic and appropriate recording of relevant activities eg logbook, diary, portfolio, spreadsheets, databases; list of resources

*Revise the initial plan as required*: methods used to review activities at the appropriate time to see if they meet requirements; make alterations as needed


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4 **Be able to monitor and evaluate own performance and learning**

*Evaluation of the quality of the work undertaken*: meeting industry standards and evaluating own performance against original proposal; comments/testimony from supervisors

*Account of learning during the work experience*: details of experience gained eg new procedures, interpersonal skills, time management, problem solving, teamwork; details of evidence eg portfolio of evidence, scientific report, management report

*Recommendations on how the learning experience could have been enhanced*: alternative ideas eg different location, different brief, different time period, more/less support, better time management, better preparation

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to negotiate industry experience | 1.1 research and evaluate suitable organisations that could provide industry experience<br>1.2 negotiate with work and academic supervisors a proposal for the work experience<br>1.3 recognise the business constraints on the work experience offered |
| LO2 Understand the specific requirements of the placement | 2.1 agree and prioritise the tasks and responsibilities involved in the work experience<br>2.2 produce a plan for the work experience<br>2.3 analyse the benefits of the proposed activities to the business and the learner |
| LO3 Be able to undertake work experience as identified | 3.1 fulfil specified requirements of placement conforming to all related codes of practice<br>3.2 produce systematic records of work undertaken<br>3.3 revise the initial plan as required<br>3.4 make suggestions for improvement and review these with appropriate supervisor |
| LO4 Be able to monitor and evaluate own performance and learning | 4.1 monitor progress against original proposal<br>4.2 evaluate the quality of own performance<br>4.3 analyse the learning which has taken place during the work experience using suitable reflections<br>4.4 make recommendations on how the experience could have been enhanced |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 29: Personal and Professional Development*
- *Unit 30: Employability Skills*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

## Delivery

This unit differs from *Unit 8: Work-based Investigation* in that a significant part of this unit relates to negotiating a placement and researching the activities of the company. In *Unit 8: Work-based Investigation*, the intention is to give credit to learners who are already industry-based and routinely develop applied science practical skills and theoretical knowledge through everyday company-based activities.

The work used for this unit must not be used for Unit 5: Project for Applied Science or Unit 8: Work-based Investigation.

Given the work-based nature of this unit, the majority of resources will be those available to learners in the workplace. Work will normally be planned to be achievable within the resource constraints of the employer. Therefore knowledge of company structures and daily routines and expectations is essential.

## Assessment

Tutor support and guidance are essential. Learners must remain in touch with tutors during the work experience. Email is often the best way but some centres may have access to a virtual learning environment where learners can share information and experiences with each other and the tutor.

## Resources

Where possible learners must negotiate a placement in a local applied science-related industry or negotiate an applied science-related scheme of work at their centre of learning. In either case they must fully appreciate the role of their placement within the context of the company's business or the centre's activity.

## Employer engagement and vocational contexts

Evaluation of learners' performance against set targets is a key aspect of the unit and must be undertaken in conjunction with both academic and industrial supervisors.

# Unit 29: Personal and Professional Development

| | |
|---|---|
| Unit code: | T/601/0943 |
| Level: | 5 |
| Credit value: | 15 |

## Aim

This unit aims to help learners become effective and confident, self-directed employees. This helps learners become confident in managing their personal and professional skills to achieve personal and career goals.

## Unit abstract

This unit is designed to enable learners to assess and develop a range of professional and personal skills in order to promote future personal and career development. It also aims to develop learners' ability to organise, manage and practise a range of approaches to improve their performance as self-directed learners in preparation for work or further career development.

The unit emphasises the needs of the individual but within the context of how the development of self-management corresponds with effective team management in meeting objectives.

Learners will be able to improve their own learning, be involved in teamwork and be more capable of problem solving through the use of case studies, role play and real-life activities.

## Learning outcomes

On successful completion of this unit a learner will:

1 Understand how self-managed learning can enhance lifelong development

2 Be able to take responsibility for own personal and professional development

3 Be able to implement and continually review own personal and professional development plan

4 Be able to demonstrate acquired interpersonal and transferable skills.

# Unit content

1 **Understand how self-managed learning can enhance lifelong development**

*Self-managed learning:* self-initiation of learning processes; clear goal setting eg aims and requirements, personal orientation achievement goals, dates for achievement, self-reflection

*Learning styles*: personal preferences; activist; pragmatist; theorist; reflector eg reflexive modernisation theory; Kolb's learning cycle

*Approaches:* learning through research; learning from others eg mentoring/coaching, seminars, conferences, secondments, interviews, use of the internet, social networks, use of bulletin boards, news groups

*Effective learning*: skills of personal assessment; planning, organisation and evaluation

*Lifelong learning*: self-directed learning; continuing professional development; linking higher education with industry, further education, Recognition of Prior Learning, Apprenticeships, Credit Accumulation and Transfer Schemes

*Assessment of learning*: improved ability range with personal learning; evidence of improved levels of skill; feedback from others; learning achievements and disappointments

2 **Be able to take responsibility for own personal and professional development**

*Self- appraisal:* skills audit (personal profile using appropriate self-assessment tools); evaluating self-management; personal and interpersonal skills; leadership skills

*Development plan:* current performance; future needs; opportunities and threats to career progression; aims and objectives; achievement dates; review dates; learning programme/activities; action plans; personal development plan

*Portfolio building*: developing and maintaining a personal portfolio

*Transcripts:* maintaining and presenting transcripts including curriculum vitae

3 **Be able to implement and continually review own personal and professional development plan**

*Learning styles and strategies*: types of styles; awareness of own personal style; impact of personal style and interactions with others

*Learning from others*: formal learning and training; observation; mentoring; supervision; tutorials; informal networks; team members; line managers; other professionals

*Evaluation of progress*: setting and recording of aims and objectives; setting targets; responding to feedback; re-setting aims and targets; establishing and recognising strengths and areas for improvement; directions for change; cycles of activity (monitoring, reflecting and planning)

4 **Be able to demonstrate acquired interpersonal and transferable skills**

*Transferable skills*: personal effectiveness (ability to communicate effectively at all levels, initiative, self-discipline, reliability, creativity, problem solving)

*Verbal and non-verbal communication:* effective listening, respect for others' opinions; negotiation; persuasion; presentation skills; assertiveness; use of ICT

*Delivery formats*: ability to deliver transferable skills using a variety of formats

*Working with others*: team player; flexibility/adaptability; social skills

*Time management*: prioritising workloads; setting work objectives; using time effectively; making and keeping appointments; reliable estimates of task time

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Understand how self-managed learning can enhance lifelong development | 1.1 evaluate approaches to self managed learning<br>1.2 propose ways in which lifelong learning in personal and professional contexts could be encouraged<br>1.3 evaluate the benefits of self-managed learning to the individual and organisation |
| LO2 Be able to take responsibility for own personal and professional development | 2.1 evaluate own current skills and competencies against professional standards and organisational objectives<br>2.2 identify own development needs and the activities required to meet them<br>2.3 identify development opportunities to meet current and future defined needs<br>2.4 devise a personal and professional development plan based on identified needs |
| LO3 Be able to implement and continually review own personal and professional development plan | 3.1 discuss the processes and activities required to implement the development plan<br>3.2 undertake and document development activities as planned<br>3.3 reflect critically on own learning against original aims and objectives set in the development plan<br>3.4 update the development plan based on feedback and evaluation |
| LO4 Be able to demonstrate acquired interpersonal and transferable skills | 4.1 select solutions to work-based problems<br>4.2 communicate in a variety of styles and appropriate manner at various levels<br>4.3 evaluate and use effective time management strategies |

# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 30: Employability Skills*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

## Delivery

Activities carried out in this unit could be part of the mainstream academic activity and could be integrated into the whole programme of study. Learners would benefit from regular review meetings, and where appropriate, linking the delivery of learning outcomes from this unit to other units.

## Assessment

A personal development portfolio or progress file must be put together for all information and personal records ‘owned’ by the learner, including the planning and monitoring of progress towards the achievement of personal objectives. The method for this could be web based, paper based or other. Potentially this could form the basis of an extended record of a lifelong record of learning and achievement.

## Resources

There are no essential resource requirements for this unit.

## Employer engagement and vocational contexts

In developing material for this unit, learners should consider any applied science industrial placements or work experience that they may have undertaken in the course of their studies.

# Unit 30: Employability Skills

Unit code: A/601/0992

Level: 5

Credit value: 15

## Aim

This unit provides learners with the opportunity to acquire honed employability skills required for effective employment.

## Unit abstract

All learners at all levels of education and experience require honed employability skills as a prerequisite to entering the job market. This unit gives learners an opportunity to assess and develop an understanding of their own responsibilities and performance in, or when entering, the workplace.

It considers the skills required for general employment, such as interpersonal and transferable skills, and the dynamics of working with others in teams or groups including leadership and communication skills.

It also deals with the everyday working requirement of problem solving which includes the identification or specification of the ‘problem’, strategies for its solution and then evaluation of the results through reflective practices.

## Learning outcomes

On successful completion of this unit a learner will:

1 Be able to determine own responsibilities and performance

2 Be able to develop interpersonal and transferable skills

3 Understand the dynamics of working with others

4 Be able to develop strategies for problem solving.

# Unit content

## 1 Be able to determine own responsibilities and performance

*Own responsibilities*: personal responsibility; direct and indirect relationships and adaptability, decision-making processes and skills; ability to learn and develop within the work role; employment legislation, ethics, employment rights and responsibilities

*Performance objectives*: setting and monitoring performance objectives

*Individual appraisal systems*: uses of performance appraisals eg salary levels and bonus payments, strengths and areas for improvement, training needs; communication; appraisal criteria eg production data, personnel data, judgemental data; rating methods eg ranking, paired comparison, checklist, management by objectives

*Motivation and performance*: application and appraisal of motivational theories and techniques, rewards and incentives, manager's role, self-motivational factors

## 2 Be able to develop interpersonal and transferable skills

*Effective communication*: verbal and non-verbal eg awareness and use of body language, openness and responsiveness, formal and informal feedback to and from colleagues; ICT as an effective communication medium; team meetings

*Interpersonal skills*: personal effectiveness; working with others; use of initiative; negotiating skills; assertiveness skills; social skills

*Time management*: prioritising workload; setting work objectives; making and keeping appointments; working steadily rather than erratically; time for learning; reliable estimate of task time

*Problem solving*: problem analysis; researching changes in the workplace; generating solutions; choosing a solution

## 3 Understand the dynamics of working with others

*Working with others*: nature and dynamics of team and group work; informal and formal settings, purpose of teams and groups eg long-term corporate objectives/strategy; problem solving and short-term development projects; flexibility/adaptability; team player

*Teams and team building*: selecting team members eg specialist roles, skill and style/approach mixes; identification of team/work group roles; stages in team development eg team building, identity, loyalty, commitment to shared beliefs, team health evaluation; action planning; monitoring and feedback; coaching skills; ethics; effective leadership skills eg setting direction, setting standards, motivating, innovative, responsive, effective communicator, reliability, consistency

4 **Be able to develop strategies for problem solving**

*Specification of the problem:* definition of the problem; analysis and clarification

*Identification of possible outcomes:* identification and assessment of various alternative outcomes

*Tools and methods:* problem-solving methods and tools

*Plan and implement*: sources of information; solution methodologies; selection and implementation of the best corrective action eg timescale, stages, resources, critical path analysis

*Evaluation*: evaluation of whether the problem was solved or not; measurement of solution against specification and desired outcomes; sustainability

# Learning outcomes and assessment criteria

| Learning outcomes<br><br>**On successful completion of this unit a learner will:** | Assessment criteria for pass<br><br>**The learner can:** |
|---|---|
| LO1 Be able to determine own responsibilities and performance | 1.1 develop a set of own responsibilities and performance objectives<br>1.2 evaluate own effectiveness against defined objectives<br>1.3 make recommendations for improvement<br>1.4 review how motivational techniques can be used to improve quality of performance |
| LO2 Be able to develop interpersonal and transferable skills | 2.1 develop solutions to work based problems<br>2.2 communicate in a variety of styles and appropriate manner at various levels<br>2.3 identify effective time management strategies |
| LO3 Understand the dynamics of working with others | 3.1 explain the roles people play in a team and how they can work together to achieve shared goals<br>3.2 analyse team dynamics<br>3.3 suggest alternative ways to complete tasks and achieve team goals |
| LO4 Be able to develop strategies for problem solving | 4.1 evaluate tools and methods for developing solutions to problems<br>4.2 develop an appropriate strategy for resolving a particular problem<br>4.3 evaluate the potential impact on the business of implementing the strategy |


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# Guidance

## Links

This unit has particular links with the following units within this qualification:

- *Unit 5: Project for Applied Science*
- *Unit 28: Work-based Experience*
- *Unit 29: Personal and Professional Development*.

This unit also links with the following NOS:

- NVQ L4 Laboratory and Associated Technical Activities (LATA).

## Essential requirements

### Delivery

Access to a range of work-related exemplars (for example appraisal and development systems, team health checks, job descriptions, action plans, communication strategies) would help in delivering this unit. Case studies based on relevant sectors, workshops, career talks, and work-based mentors would also be useful in the teaching and learning aspect of the unit.

### Assessment

Learners can generate assessment evidence through a range of possible activities including individual work placements, project management, research reports, development of case studies, working with others (for example employee – supervisor roles, teamwork, group work) and everyday communication within the workplace.

### Resources

There are no essential resource requirements for this unit.

### Employer engagement and vocational contexts

In developing material for this unit, learners must consider any applied science industrial placements or work experience that they may have undertaken in the course of their studies.